Volume XXII July, 1926 Number 1

SOIL SCIENCE

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Contents

PUBLISHED MONTHLY
THE WILLIAMS & WILKINS COMPANY
MT. ROYAL AND GUILFORD AVENUES
BALTIMORE, MARYLAND, U. S. A.

Made in United States of America

SOIL SCIENCE

FOUNDED BY
RUTGERS COLLEGE
NEW BRUNSWICK, N. J.

EDITORIAL BOARD

Entered as second-class matter May 12, 1919, at the post office at Baltimore, Maryland, under the act of March 3, 1879

SWEET CLOVER IN RELATION TO THE ACCUMULATION, LOSS AND CONSERVATION OF NITRATES IN SOIL

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Received for publication November 13, 1925

The value of biennial white sweet clover when plowed under green, was emphasized by the authors in earlier publications (6, 7).

Maynard (1) made a study of the decomposition of this same variety under greenhouse conditions and reported that the three to four months' growth decayed very rapidly when used as a green manure. McBeth (2) tested green sweet clover in comparison with green oats, green barley, and green alfilaria and found the sweet clover easily the leader in nitrate production. In field trials with various legumes and non-legumes Mertz (3) found the annual sweet clover (*Melilotus indica*) the most promising winter green manure for southern California. The value of *Melilotus alba* for use as a green manure and for summer pasture was emphasized by Metzger (4) who recommended plowing it under when 8 to 10 inches high; and still more recently its importance has been pointed out by Moore and Graber (5) and by Fraser (5). Since the completion of this work Willard (8) has made a study of the yield and nitrogen content of white sweet clover at different dates. His results are in agreement with those already reported by the authors (7) and those occurring in this paper. He advises plowing between April 15 and May 10. On May 10 he found as much nitrogen as was found even as late as August 8. The weights of stubble and roots and the final stand per acre are reported by him.

Further studies were conducted by the authors on nitrification of the sweet clover as influenced by fall and spring plowing, spring plowing at different dates, and summer plowing of the crop the second year. Losses resulting from the last named practice and means of preventing it, and the rôle sweet clover plays in conserving soil nitrates during the fall, winter, and spring were also a part of this investigation. Important factors influencing the accumulation and the rate of production were next taken up from practical standpoints in the field. Attention was directed toward accumulations in the absence of succeeding crops with the purpose of studying nitrate conservation. The pro-

[1] The authors wish to express their appreciation of the excellent cooperation afforded by the experiment field staff of the agronomy department of the University of Illinois during the progress of this work.

The senior author is at present connected with the University of Wisconsin, and the junior author is on the Ohio State University staff.

tective action of sweet clover on soil, especially on the nitrates, was made a special study on experiment fields because the conservation of nitrates in often of equal importance to their accumulation.

Nitrate production in a soil together with nitrate utilization is only one factor concerned with crop production and, although a large factor in crop yields, is not necessarily related to crop yields unless optimal amounts of all other elements are present in optimal forms at all times. The highest nitrate producing plots can not give the largest yields if phosphorus, or any other factor of whatever kind, is in any manner limiting production.

Nitrogen must needs be studied as a single factor concerned with crop production, until studies of other elements meet the progress made on this element.

The studies that follow are concerned with practical field problems of controlling nitrate accumulation, conserving unused nitrates, and protecting the soil from losses, as related to the growth and plowing under of biennial white sweet clover (*Melilotus alba*).

NITRIFICATION OF FALL- VERSUS SPRING-PLOWED SWEET CLOVER, JOLIET EXPERIMENT FIELD—1921–1922

In order to study the effect of fall plowing compared with spring plowing of sweet clover, on its value for nitrate production for corn, Series 300 of the Joliet Field was divided, and the east half plowed in November and the west half in May.

Excellent plowing was accomplished in the fall, cutting the roots off completely at about seven inches, and turning the tops under properly. Samples were taken on both halves of the plots on November 25.

The plots selected for study were as follows:

Plot 305—no treatment.
Plot 307—limestone and sweet clover.
Plot 308—limestone, phosphorus, and sweet clover.
Plot 309—limestone, phosphorus, potassium, and sweet clover.

The sweet clover was in excellent condition on plot 309, good on 308, and fair on 307. In the early spring, the fall-plowed sweet clover began to grow, sending out many shoots from the crown of the old root and developing new feeding roots from the old root stock. A severe winter had not killed it, and it grew so fast that it made a fair stand. It was double-disked, but still it grew and finally it was plowed again in the spring about May 7 at the same time the west half was plowed. This experience with fall plowing of biennial sweet clover was not encouraging.

On May 5, before the spring plowing, samples were taken. The unplowed sweet clover was 14 inches high on plot 309 West, 12 inches on plot 308 West, and about 8 inches in height and irregular on plot 307 West. Spring rains kept the nitrates low up to May 5.

On July 6, the corn crop on this series showed the following differences in height:

Plot	*Height in inches*
305-E	17
305-W	20
307-E	18
307-W	32
308-E	24
308-W	36
309-E	30
309-W	40

The differences between the east and west halves were evident a considerable distance from the field until the corn became mature.

The reason for the difference in favor of the spring plowing was not easy to determine. In table 1 are given the nitrate results on the east and west halves.

TABLE 1

Nitrate nitrogen in soil on Joliet Field, fall of 1921 and season of 1922

[Pounds per acre in 2 million pounds of surface soil (about 0–6⅔ inches) water-free basis]

PLOT	TREATMENT	PLOWED	NITRATE NITROGEN ON DATE OF SAMPLING				
			November 25	May 5	June 7	July 6	August 18
305-E	0	Fall	16.21	19.41	29.13	32.82	56.18
305-W	0	Spring	15.22	15.50	24.91	23.11	29.74
307-E	L sweet clover	Fall	14.04	17.62	51.23	58.31	187.90
307-W	L sweet clover	Spring	12.80	19.78	59.06	61.21	113.00
308-E	LP sweet clover	Fall	13.76	15.48	91.47	70.76	83.32
308-W	LP sweet clover	Spring	15.82	5.91	97.24	63.76	67.36
309-E	LPK sweet clover	Fall	17.67	20.42	65.95	60.94	83.51
309-W	LPK sweet clover	Spring	17.04	7.48	89.85	74.10	158.38
309-E	LPK sweet clover	Fall	Subsoil*	29.52	50.98	37.97	
309-W	LPK sweet clover	Spring	Subsoil*	11.00	51.90	64.32	

* In 6 million pounds of subsoil.

The nitrate content in the fall on November 25 was low in the surface soil and showed only slight differences between the east and west sides. These results show that the nitrate content of the surface soil had been reduced by a nearly uniform amount as a result of the 11 inches of rain from September to December. Although the checks showed 16.21 and 15.22 pounds in the surface soil, it must be remembered that the treated plots contained about the same amount of nitrate nitrogen, and in addition at least 100 pounds of nitrogen in the sweet clover crop whether plowed or unplowed. This important difference must not be overlooked in comparing the plots. The nitrogen in the crop is saved for another year. In the spring after 12.55 inches of rain, and with the growth of the crop on the treated plots, the nitrate was reduced on the 309 and 308 plots to very low figures. On plot 307 where the poorest

sweet clover was growing, an increase occurred. The checks also increased slightly. On plots 308 and 309 East and West, the nitrate results followed the corresponding sweet clover growths. The usual increases in nitrate content occurred after plowing and with the coming of increased temperatures. The treated plots showed much the highest nitrates at all times. The phosphorus and potassium plots, 308 and 309, in spite of the fact that they were supporting better corn, showed the highest nitrate content during the important feeding period for the corn crop.

The nitrate content of the subsoil of 309 East and 309 West showed the sweet clover had reduced it by its spring growth on the west side. After plowing, an increase in nitrate occurred in the subsoil. The differences in nitrate content between the fall plowing on the east side and the spring plowing on the west side, are not significant except on plot 309. The largest growth of sweet clover was plowed under on 309 West and here the largest nitrate occurred. The fact that all the nitrate figures are so far in excess of the other factors of growth shows that nitrogen was not limiting the growth of the corn.

The physical condition of the soil on the east side was very bad, whereas it was ideal on the west side. The spring disking and replowing of the east side gave a cloddy formation that endured all through the season. The large differences in the condition of the corn on the two halves may have been due to the poor physical condition of the east half. It is evident that the fall growth of sweet clover combined with its spring growth, in spite of twice double-disking on the east halves, furnished nitrates enough for about twice the crop obtained. The corn yields on the east and west halves did not differ by reliable differences, being only 1.8 bushels in favor of the east side on 308 and 1.4 bushels better on the west side of 309.

The yields on this series indicate clearly that phosphorus and potassium are not present in sufficient amounts in an available form to give as high corn yields as do nitrogen and limestone.

Such nitrate data are encouraging from the standpoint of the nitrogen problem, and clearly indicate, as has been shown (6, 7), that nitrification is ahead of crop requirements where proper soil treatment is applied, and where sweet clover is used repeatedly as a green manure in a 4-year rotation.

The nitrate results for August 18 are very high. These high amounts of nitrate in the surface of the soil are credited to a rise of nitrate from below that had not been lost from the subsoil, but which may be lost in the fall or the winter. The surface soil contained only 8.5 to 11.85 per cent of moisture on August 18. These percentages will not support nitrification in this soil. Similar nitrate concentrations in the surface will be presented in the data from other fields. This upward movement is an important consideration, especially at this time of year. Its recognition affords an opportunity to save the nitrate and thus to avoid undue losses.

Fall plowing on this field furnished more nitrate than was needed for one large corn crop. This makes desirable the finding of a satisfactory method

of fall plowing, as in some rotations the amount of nitrates here produced would be ample. This study indicates that spring plowing of green sweet clover is better than fall plowing, when all conditions such as nitrate production, physical condition, and lessened mechanical labor are considered.

NITRIFICATION OF SWEET CLOVER SPRING PLOWED AT DIFFERENT DATES, HARTSBURG AND TOLEDO EXPERIMENT FIELDS—1921

The effect of varying the date of plowing, on the recognized value of green sweet clover as a nitrate producer was studied in 1921 on the Hartsburg Experiment Field, in Logan County, and on the Toledo Experiment Field, in Cumberland County.

Hartsburg Experiment Field

The soil of the Hartsburg Field is of a heavy type, being classified as a black clay loam. Sweet clover will make a limited growth on the unlimed plot on this field.

The east side of series 300 was plowed on May 4 and the west side on May 13. Samples of the sweet clover were taken for analysis to determine the rate of nitrogen gain per acre. Unfortunately for this study some of the sweet clover was frozen three and some four times. The green weights and water-free weights of the crop at the time of plowing were determined and are reported in table 2.

The nitrate determinations in the surface soil are also arranged in table 2. The first samples were taken May 3. Some variations are evident between the east and west sides, especially on the treated plots. That the sweet clover stand was irregular was probably a contributing cause of the variations, as they are confined to given plots and do not carry across plot lines. The treated plots on which sweet clover had grown very well in the fall and only fairly in the spring, contained more nitrates than the checks where a poor growth of sweet clover was present.

As anticipated, the nitrates increased more rapidly on the east half after plowing, than on the unplowed west half, up to May 17. Both halves, however, increased; even the west side almost doubled in nitrate content. The cold weather apparently affected the growth of the sweet clover relatively more than it reduced the activity of the nitrifying bacteria. After some heavy rains the nitrate was reduced materially on all plots except 309, where the growth of sweet clover had been best. On June 22, the later plowing on the west sides contained much the larger amounts of nitrate, except on plot 308, both sides of which were, however, very high. Nitrates continued to accumulate on the east side although to a smaller extent. From July 1 to 15, conditions were highly favorable for the rise of nitrates from below through evaporation, although some was probably produced as the moisture did not fall to a prohibitive point on this field as it did on the Joliet Field. The large quantities

TABLE 2

Nitrate nitrogen in soil growing corn in 1921—Hartsburg Field sweet clover plowed May 4 and May 13

[Per acre in 2 million pounds of surface soil (about 0–6⅔ inches) water-free basis]

PLOT	TREATMENT	PLOWED	WEIGHT OF SWEET CLOVER (TOPS ONLY)		NITRATE NITROGEN IN SOIL ON DATE OF SAMPLING								
			Green	Water-free	May 3	May 11	June 8	June 22	July 1	July 15	July 29	August 24	September 30
			tons	*tons*	*lbs.*	*lbs.*	*lbs.*	*lbs.*	*lbs.*	*lbs.*	*lbs.*	*lbs.*	*lbs.*
305-E	0	May 4			15.7	61.9	30.7	29.0	35.9	78.0	52.7	28.54	26.1
305-W	0	May 13			17.6	56.9	26.6	66.3	34.8	71.9	57.0	28.5	20.0
306-E	R sweet clover	May 4	4.69	0.837	21.5	84.9	38.6	34.7	61.5	101.5	81.0	49.7	42.8
306-W	R sweet clover	May 13			27.7	57.0	28.7	69.0	55.0	81.4	72.8	52.4	41.6
307-E	RL sweet clover	May 4	4.30	0.731	25.2	88.7	34.4	53.0	90.6	78.7	75.0	46.1	28.9
307-W	RL sweet clover	May 13			31.3	67.5	33.4	65.3	81.4	73.8	65.5	45.4	22.0
308-E	RLP sweet clover	May 4	3.77	0.674	37.3	80.5	45.4	99.4	102.0	108.5	104.5	44.9	29.4
308-W	RLP sweet clover	May 13			33.1	60.2	39.4	81.4	84.1	103.4	97.2	41.7	30.2
309-E	RLPK sweet clover	May 4	5.73	1.010	33.2	73.2	62.6	83.1	81.5	92.0	75.1	36.1	30.5
309-W	RLPK sweet clover	May 13	6.36	1.280	37.7	69.6	63.9	112.5	75.8	95.7	72.7	32.4	26.6
310-E	0	May 4			17.6	58.4	26.0	34.6	47.3	56.1	52.1	20.0	28.2
310-W	0	May 13			19.7	57.1	22.1	24.1	48.5	47.8	35.5	18.1	26.1

Plots 306, 307 and 308-W killed by frost, no samples taken.

of nitrate found are indicative of the success attained in its production by proper soil treatment, including the use of green sweet clover. A corn crop of fifty to sixty-three bushels was being produced and the figures show that nitrate was not a limiting factor in production on this field. The presence of such large amounts of nitrate nitrogen during the critical feeding period, is proof that the production phase of the nitrogen problem is satisfactorily solved for such soils, until such a time as much larger crops are possible.

During August and September, as far as the surface soil is concerned heavy rainfall seriously reduced the nitrate content which fell from as high as 108 pounds to as low as 29. If this difference of 79 pounds was permanently lost, it means a serious depletion of the most expensive element, and its conservation by crop growth, by bacterial action, or by both, is highly desirable as the next important step in the solution of the nitrogen problem.

The average nitrate contents of the treated and untreated plots are given in table 3. The differences are interesting, as the checks are not acid, which

TABLE 3

Average of nitrate nitrogen on treated and untreated plots on Hartsburg Field, 1921

[Pounds per acre in 2 million pounds of surface soil (about 0–6⅔ inches) water-free basis]

PLOT	NITRATE NITROGEN AVERAGES ON DATES OF SAMPLING								
	May 3	May 17	June 8	June 22	July 1	July 15	July 29	August 24	September 30
Treated	30.90	72.70	43.30	74.80	78.99	91.88	80.45	43.57	31.50
Untreated	17.65	58.58	26.35	38.65	41.60	63.45	49.40	23.78	25.08
Increase for treatment	13.25	14.12	16.95	36.15	37.39	28.43	31.05	19.79	6.42

means that the increases found are largely due to the sweet clover and that they have occurred on a type of soil regarded as highly productive before sweet clover was used on it.

There was no important advantage, from a nitrogen standpoint, in either the May 4 or May 17 plowing dates, as both produced excessive nitrates for the critical feeding period. The organic matter and the other elements of plant-food contained in the sweet clover would be increased by allowing the crop to remain as long as possible before plowing.

Toledo Experiment Field

The Toledo Experiment Field, in Cumberland County, in southeastern Illinois, is located on gray silt loam underlain with tight clay. This type of soil without treatment produces poor yields.

The south half of series 300, was plowed May 1, and the north half, May 16. Sweet clover samples were taken and the data on green and dry weights

TABLE 4

Nitrate nitrogen in soil growing corn in 1921 Toledo Field sweet clover plowed May 1 and 16

[Per acre in 2 million pounds of surface soil (0–6⅔ inches) water-free basis]

PLOT	TREATMENT	PLOWED	WEIGHT OF SWEET CLOVER (TOPS ONLY)		NITRATE NITROGEN IN SOIL ON DATE OF SAMPLING									
			Green	Water-free	April 22	May 4	May 14	June 7	June 23	June 30	July 14	July 27	August 25	September 29
			tons	*tons*	*lbs.*	*lbs.*	*lbs.*	*lbs.*	*lbs.*	*lbs.*	*lbs.*	*lbs.*	*lbs.*	*lbs.*
305-S	0	May 1			15.4	20.2	35.9	16.4	17.1	31.9	65.1	40.4	31.9	24.0
305-N	0	May 16			7.6	11.6	34.5	15.8	20.5	34.9	63.8	39.4	22.0	26.6
306-S	R	May 1			23.4	23.2	34.3	19.3	19.6	30.7	64.9	43.2	21.5	23.5
306-N	R	May 16			7.7	20.9	36.5	21.9	19.5	28.2	69.6	39.9	18.6	23.2
307-S	RL sweet clover	May 1	2.83	0.560	23.5	22.5	68.9	43.4	26.2	63.3	103.0	82.3	43.2	44.8
307-N	RL sweet clover	May 16	5.80	1.052	22.9	25.2	55.4	44.5	25.4	53.7	114.2	77.8	34.5	35.8
308-S	RLP sweet clover	May 1	2.10	0.421	23.1	19.3	66.7	46.6	57.7	57.2	100.4	74.9	38.1	40.1
308-N	RLP sweet clover	May 16	5.27	0.923	15.4	20.7	49.3	43.1	50.7	53.8	90.9	84.5	33.0	33.5
309-S	RLPK sweet clover	May 1	4.23	0.794	23.0	19.6	56.9	58.0	65.0	76.6	107.5	105.0	46.9	35.6
309-N	RLPK sweet clover	May 16	11.78	1.840	30.6	22.8	40.0	60.4	24.5	100.6	113.2	89.4	36.6	34.5
310-S	0	May 1			23.1	9.7	30.3	23.8	17.7	30.9	64.7	53.5	32.0	23.2
310-N	0	May 16			7.7	11.7	35.0	20.5	19.7	29.4	67.3	50.0	17.8	24.8

are found in table 4. The dry weight of the sweet clover tops doubled in the 15-day interval.

The nitrate content of the south side was greater on May 14, thirteen days after plowing. The north side showed less regularity in surpassing the south side, even as late as July 14. Ample nitrate was produced on both sides of the plots. A very poor crop was present on the checks which accounts in part for their high nitrate content, but most of the nitrate accumulation on the checks is ascribed to the rest period which this series enjoyed through three successive crop failures. On this field, the different dates of plowing did not show sufficient difference in the nitrate content to affect the crop. A large surplus was present during the critical feeding period.

The excessive amounts in the surface soil were derived from the lower layers and not from the amount manufactured in the surface at that time, as the moisture was very low during July, ranging from 6.4 per cent on plot 309 to 11.6 per cent on the check plot 310. The rainfall was 1.92 inches for July, 5.94 inches for August, and 8.59 inches for September. The accumulation under excessively dry soil conditions is again explained by a rise of nitrates. The great losses from the surface soil due to rain, are again apparent. Plots 307, 308, and 309 averaged 104.8 pounds of nitrate nitrogen on July 14 and only 38.71 on August 25 and 37.36 pounds on September 29. A loss of about 67 pounds occurred during this period. On this type of soil with an impervious subsoil, the nitrate may not leach out, as this land is not tile drained, but it may be lost through denitrification when conditions of moisture and temperature are favorable. On properly tiled land a loss would result from leaching.

TABLE 5

Average of nitrate nitrogen of treated and untreated soil on Toledo Field, 1921

[Pounds per acre in 2 million pounds of surface soil (about 0–6⅔ inches) water-free basis]

PLOT	NITRATE NITROGEN ON DATE OF SAMPLING									
	April 22	May 4	May 14	June 7	June 23	June 30	July 14	July 27	August 25	September 29
Treated	23.10	21.70	56.20	51.00	41.60	67.50	104.90	85.65	38.71	37.38
Untreated	14.15	16.20	34.40	19.60	19.00	31.00	65.90	44.40	23.95	24.21
Increase for treatment	8.95	5.50	21.80	31.40	22.60	36.50	39.00	41.25	14.76	13.17

In tabie 5, the average nitrate nitrogen contents of the untreated and the treated plots are reported. Treated soil growing sweet clover furnished much larger amounts of nitrates (in spite of the fact that these plots were producing much larger crops) than the checks.

It is evident that on this field, as on the others studied, the nitrogen requirements have been much more successfully met than the other factors concerned

in production. Lack of sufficient moisture, injury due to hot winds, lack of available phosphorus, or lack of some other element than nitrogen, must be regarded as the cause of limited crop growth on this field.

Data on the height, green weight, percentage of nitrogen, and amount of nitrogen in the tops per acre, are given in table 6. The increases in nitrogen in the tops per acre are apparent on the various dates of sampling. The crop contains over 80 pounds of nitrogen per ton on both these fields, except on May 14 and 17. Delaying the plowing, greatly increases the weight of organic matter and the nitrogen per acre in the tops. These figures would appear to represent the minimum, as the exceptionally cold weather accompanied by repeated freezes delayed the growth of the sweet clover more than in any other season noted.

TABLE 6

Weights and nitrogen content of sweet clover tops of spring growth, 1921

(Acre basis)

FIELD	PLOT	DATE SAMPLE WAS TAKEN	HEIGHT	GREEN WEIGHT	WATER	WEIGHT OF WATER	WATER-FREE MATERIAL		WEIGHT OF NITROGEN IN TOPS
							Weight	Nitrogen	
			inches	*tons*	*per cent*	*tons*	*tons*	*per cent*	*lbs.*
Toledo	307-S	April 22	6	2.420	85.68	2.073	0.346	4.26	29.5
	308-S	22	5	1.960	85.20	1.670	0.290	4.44	25.7
	309-S	22	8	4.840	87.33	4.227	0.613	4.34	53.2
	307-S	May 4	8	2.831	80.21	2.271	0.560	4.44	49.7
	308-S	4	7	2.105	80.00	1.684	0.421	4.30	35.4
	309-S	4	13	4.235	81.23	3.440	0.794	4.22	67.0
	307-N	14	18	5.808	81.87	4.755	1.052	3.74	78.7
	308-N	14	17	5.275	82.19	4.352	0.923	3.60	67.4
	309-N	14	24	11.785	84.33	9.939	1.845	3.74	138.0
Hartsburg	306-E	May 3	6	4.694	82.17	3.857	0.837	4.42	73.9
	307-E	3	6	4.307	83.02	3.576	0.731	4.44	64.9
	308-E	3	6	3.777	82.14	3.103	0.674	4.50	60.7
	309-E	3	8	5.735	82.32	4.721	1.013	4.22	85.5
	309-W	17	20	6.364	79.76	5.076	1.288	3.88	100.0

The need for delaying the plowing of sweet clover on this type of soil is most urgent in the initial use of the crop. After it has been grown two or more times on the same soil, it may be plowed earlier without sufficiently reducing the accumulation of nitrate to limit the corn crop.

NITRIFICATION OF SUMMER PLOWED SWEET CLOVER, BLOOMINGTON, ILLINOIS

Through the coöperation of the Bloomington Canning Company and the McLean County Farm Bureau, an opportunity to study nitrate accumulation and losses was available where second year sweet clover was plowed

under. The soil of this field is a brown silt loam and had been limed. The sweet clover was about 6 feet high when plowing began about July 22. The tops were still green and seed had not yet formed. There were 100 acres of the section in second year sweet clover.

The question arose as to the loss of nitrates that might result from plowing while the crop was still green and with about ten months intervening before the sweet corn would be planted. It was suggested that oats and rye be seeded on adjacent plots and these together with a fallow check would be sampled for nitrate accumulation and losses. The purpose of seeding these

TABLE 7

Nitrate nitrogen in soil at Bloomington, Illinois: Field of Bloomington Canning Company. Plowed under the Last of July, 1921

(Water-free basis)

TREATMENT	POUNDS OF NITRATE NITROGEN IN SURFACE, SUBSURFACE, AND SUBSOIL			
	October 1 1921	November 3 1921	May 4 1922	July 5 1922
Fallow:				
Surface, 0–7 inches	78.5	103.3	7.8	40.9
Subsurface, 7–20 inches	83.7	107.2	29.2	60.5
Subsoil, 20–40 inches	60.2	92.5	56.3	77.9
	222.4	303.0	93.3	179.3
Rye:				
Surface, 0–7 inches	64.6	34.5	9.7	51.5
Subsurface, 7–20 inches	107.2	94.0	34.7	61.3
Subsoil, 20–40 inches	99.0	85.7	62.4	82.2
	270.8	214.2	106.8	195.0
Subsoil, 40–80 inches	182.4	182.2	127.8	160.3
Oats:				
Surface, 0–7 inches	56.2	29.5	27.9	50.3
Subsurface, 7–20 inches	84.6	63.1	48.9	46.6
Subsoil, 20–40 inches	85.2	91.2	69.9	50.4
	226.0	183.8	146.7	147.3

crops at this time was to determine their value for conserving the nitrates that would be produced from the green sweet clover. Plots of about one-fourth acre in area were arranged at the northeast corner of the field. Samples were taken soon after plowing and on August 25, about one month later but before the small grains were seeded. The surface soil contained 77.8 pounds of nitrate nitrogen per acre on July 29 and 49.1 on August 25. There was 10.44 inches of rain in August which accounts for the reduction noted. Beginning October 1, samples were taken of the three plots at three depths and a few samples were taken as deep as 80 inches.

From table 7 it is evident that the sweet clover increased the nitrate con-

tent of the fallow soil, as on November 3 about 103.3 pounds was found in the surface, 107.2 in the subsurface, and 92.5 in the subsoil or a total of 303.0 pounds in 40 inches. This was from two to three times as much as the highest producing experiment fields sampled at the same time and in the same manner. The much lower nitrate content of the oat and rye plots is evident in the surface and subsurface. The amount of nitrates in the subsoil was about the same as that of the fallow, which may be accounted for by the heavy rain which washed the soil equally on all plots before the oats and rye grew sufficiently to use nitrates and to offer protection against its descent. The oats attained a height of 14 inches and covered the ground. The rye was a thin stand, but stooled out to make a fair stand about 4 inches high by November 3. There was a difference of 88.8 pounds between the fallow and the rye plots and 119.2 pounds between the fallow and the oats plots on November 3. Such differences are not to be accounted for only in the crops. The actual conservation of nitrogen, as shown by the oat plot, was probably greater than shown by the figures, because on the fallow plot the initial nitrification was more complete, whereas on the other plots it was delayed at certain periods

TABLE 8

Distribution of nitrate by inches sweet clover field of Bloomington Canning Company, 1921

(Pounds per inch)

LAYERS	FALLOW	RYE	OATS
Surface, 0–7 inches	14.7	4.9	4.2
Subsurface, 7–20 inches	8.2	7.2	4.8
Subsoil, 20–40 inches	4.6	4.3	4.6
Subsoil, 40–80 inches	4.6	4.6	

by the presence of the crops. In the spring the oats plot, as expected, contained the highest nitrate in the surface soil. The rye grew until disked in. The nitrate on this plot was only 9 pounds. The fallow plot suffered a loss from leaching and therefore contained only 7 pounds. In July when the sweet corn was growing rapidly, there was an excess of nitrate on all plots.

The oat plot was the most efficient and the most economical in the utilization of the nitrate. It contained about 50 pounds more than the fallow on May 4. July 5, it was the lowest of the three plots, which as in the previous year, would mean smaller losses.

Soil that possesses the least nitrate in the fall, sufficient preceding and an excess during the critical feeding period of the crop, and the least after meeting this feeding period is the most desirable for the corn crop. Such a soil must possess the potential capacity to produce ample nitrate, as did this soil.

The distribution of the nitrate nitrogen by inches in the various layers, as seen in table 8, shows readily the efficiency of these crops in checking the downward movement of the nitrates in the subsurface where the effect would be most easily determined. The conservation of nitrates is also readily seen

from this table. With a growing crop on the surface soil, a conversion is taking place at the same time that a reduced nitrification occurs, which means a supply of organic nitrogen for nitrification at a later period. Volunteer oats and other grains function in a limited degree in the manner indicated here. In cases where land is not to be used for growing other crops, allowing sweet clover to reach maturity will greatly increase the organic matter content of the soil and provide nitrate nitrogen for two corn crops. When the crop is left for seed the rate of nitrification is, however, advantageously delayed and fall and spring losses are reduced. The volume of organic matter is not so great when the crop is left for seed as when plowed under green at an earlier stage of maturity.

The above method of handling sweet clover is not so valuable as plowing it under green in the spring because a year is not lost in growing a money crop. The magnitude of the losses that may occur are evident from this study and are perhaps as large here as would be met under almost any other condition, because of the large interval occurring between plowing the green, rapidly decomposing crop and planting the succeeding crop, and of the excessive fall and spring rains of that period.

Sweet clover as a nitrate producer is further demonstrated in this investigation at Bloomington.

LOSS OF NITRATE ON ILLINOIS EXPERIMENT FIELDS, 1921–22

It was the purpose of this study to determine the amount of nitrate lost from the 40-inch layer of the soil during the winter and early spring and the effect of the treatments on reducing losses.

Plot 404, which receives manure, limestone, and phosphate; the adjacent check, and the nearest sweet clover plot receiving limestone and phosphate, were selected on eight fields in northern and central Illinois, and on five in southern Illinois.

Fall samples were collected in November and December. The Dixon, Mount Morris, La Moille, and Spring Valley samples were taken from under 2 to 4 inches of snow. The remainder of the samples from the northern and central fields were taken after continuous rains and with the soil very wet. The samples from the southern fields were taken after heavy rains.

In table 9, the pounds of nitrate per acre in surface, subsurface, and subsoil in the fall and spring are reported. The differences represent the amounts lost. The totals are found in the last three columns at the right. Where a gain occurred a plus sign appears before the figures; all other figures are losses. Manure had been spread on all the northern fields; this would increase the losses found.

It should be understood that wide variations occur in the soil types among these fields and in most cases on a given field. The plots included in the study on the Dixon field extended over two phases of brown silt loams; on the Spring Valley field one phase of brown silt loam only entered into the

TABLE 9

Loss of nitrate nitrogen on Northern and Central Illinois Experiment Fields during the winter and spring of 1921–22

(Pounds per acre)

FIELD	DATE	SURFACE			SUBSURFACE			SUBSOIL			TOTAL		
		404	405	408	404	405	408	404	405	408	404	405	408
Dixon	Fall	18.36	21.24	18.07	34.29	34.22	30.00	43.21	56.09	37.41	105.86	111.55	85.48
	Spring	17.17	4.62	16.23	24.28	20.68	29.62	33.90	25.53	39.40	75.35	50.83	85.25
	Loss	1.19	16.62	1.84	10.01	13.54	0.38	19.31	30.56	+1.99	30.51	60.72	0.23
Mount Morris	Fall	22.05	23.24	19.27	34.34	52.60	28.42	46.05	53.27	52.41	102.44	129.11	90.10
	Spring	10.56	15.84	12.75	29.32	23.58	29.79	29.64	65.63	53.38	69.52	106.05	95.92
	Loss	11.49	7.40	6.52	5.02	29.02	+1.37	16.41	+12.36	+10.97	32.92	23.06	+5.82
LaMoille	Fall	44.39	40.28	38.51	52.19	48.73	59.48	39.27	42.24	83.12	135.85	131.25	181.11
	Spring	11.98	8.01	20.84	19.06	19.22	19.04	22.54	22.68	28.18	53.58	49.91	68.06
	Loss	32.41	32.27	17.67	33.13	29.51	40.44	16.73	19.56	54.94	82.27	81.34	113.05
Spring Valley	Fall	14.58	15.41	18.38	35.58	26.39	30.07	39.39	37.20	46.73	89.55	79.00	95.18
	Spring	12.92	12.55	16.36	18.10	18.41	29.16	21.92	16.65	50.12	52.94	47.61	95.64
	Loss	1.66	2.86	2.02	17.48	7.98	0.91	17.47	20.55	+3.39	36.61	31.39	+0.46
Kewanee	Fall	24.24	28.13	29.49	46.73	56.60	46.51	51.28	68.31	53.99	122.25	153.04	129.99
	Spring	12.48	14.20	16.16	56.16	24.21	27.77	41.95	53.61	24.10	110.59	92.02	68.03
	Loss	11.76	13.93	13.33	+9.43	32.39	18.74	9.33	14.70	29.89	11.66	61.02	61.96
Aledo	Fall	22.45	19.34	18.70	37.37	29.64	30.51	34.04	31.55	31.20	93.86	80.53	80.41
	Spring	13.60	9.76	16.05	34.02	34.52	39.43	33.47	34.32*	45.95	81.09	78.60	101.40
	Loss	8.85	9.58	2.65	3.35	+4.88	+8.92	0.57	+2.77	+14.75	12.77	1.93	+20.99

Oquawka	Fall	11.45	9.68	15.57	24.55	19.64	26.21	37.29	43.97	34.34	73.23	73.29	76.12
	Spring	8.45	3.12	6.70	16.19	9.80	15.25	44.05	20.70	9.57	68.69	33.62	31.52
	Loss	3.00	6.56	8.87	8.36	9.84	10.96	+6.76	23.27	24.77	4.54	39.67	44.60
Carthage	Fall	12.07	10.97	18.29	29.33	25.26	25.15	31.83	28.94	28.80	73.23	65.17	72.24
	Spring	9.53	5.77	17.04	18.90	11.42	24.63	28.90	23.10	17.02	57.33	40.29	58.69
	Loss	2.54	5.20	1.25	10.43	13.84	0.52	2.93	5.84	11.78	15.90	24.88	13.55

* One determination only.

plots; on the La Moille field a black silty clay loam, a black clay loam, and a brown silt loam entered in; on the Mount Morris field a light brown silt loam and a light brown silt loam shallow phase were included in the plots; on the Kewanee field all plots occur on the brown silt loam; a similar condition exists on the Aledo field; on the Carthage field a black silty clay loam on clay and a grayish brown silt loam on tight clay were the types on the plots selected. The Oquawka and Palestine fields are sands.

Toledo, Newton, and Oblong are gray silt loams on tight clay. West Salem is a yellow gray silt loam. These four southern fields and Palestine represent types of soil which respond in a large way to treatment. The sweet clover plots (numbers 408) of the northern and central groups, lost the smallest amount or gained on the Dixon, Mount Morris, Spring Valley, Aledo, and Carthage fields. The manure plots (numbers 404) lost the smallest amount on two fields of this group, Oquawka and Kewanee. The checks lost the largest amounts on Dixon, Kewanee, and Carthage. On the La Moille field, the check and manure plot lost about the same amount.

The loss of nitrate nitrogen irrespective of the crop on the sweet clover plots was 206; on the manure 227; and on the check 325 pounds per acre. The average reductions in loss on the northern and central fields were as follows:

	pounds per acre less than check plots
Sweet clover plots (408)	119
Manure plots (404)	98

In addition to the reduction of losses, the sweet clover contained at least 100 pounds and probably 150 pounds of nitrogen, a part of which was originally nitrate that would otherwise have been lost.

The percentage loss in most cases was greatest on the check plots. Where the largest amounts were present, the loss was somewhat dependent upon the contour of the field, as on the La Moille field. On the Kewanee field, the foxtail was an important factor in preventing much larger losses.

These studies were made during a season of disastrous rainfall—September and March were about four times the normal rainfall and April was only a little under March for most of the fields.

The outstanding value of sweet clover on these fields in reducing the losses of nitrate nitrogen by protecting the soil and as a conserver of nitrogen, needs no further comment.

On the southern fields, which contain much less nitrate under most conditions, the losses were small both actually and on a percentage basis. There is a possibility that early spring nitrification reduced some of the losses. That the manure plots gained on three fields, on which the sweet clover was growing, supports this view, for the growth of sweet clover would increase the apparent loss of nitrogen by conversion. When the large sweet clover crops on these fields, as on the others studied, are taken into consideration, the ap-

TABLE 10

Loss of nitrate nitrogen on Southern Illinois Experiment Fields during the winter and spring of 1921–22

(Pounds per acre)

FIELD	DATE	SURFACE			SUBSURFACE			SUBSOIL			TOTAL		
		404	405	408	404	405	408	404	405	408	404	405	408
Toledo	Fall	11.64	11.71	11.30	17.13	18.92	19.43	25.44	22.57	22.50	54.21	53.20	52.33
	Spring	5.81	5.77	11.63	22.39	11.34	19.13	28.71	23.19	11.19	56.91	40.30	41.95
	Loss	5.83	5.94	+0.33	+5.26	7.58	0.30	+3.27	+0.62	11.31	+2.70	12.90	10.38
Newton	Fall	9.60	10.52	13.30	32.66	23.37	20.57	27.08	30.93	23.84	69.34	64.82	57.71
	Spring	9.05	5.65	5.57	41.33	18.90	7.36	26.35	26.97	20.89	76.73	51.52	33.82
	Loss	0.55	4.87	7.73	+8.67	4.47	13.21	0.73	3.96	2.95	+7.39	13.30	23.89
Oblong	Fall	12.80	11.74	12.57	23.22	19.04	18.00	31.32	19.85	37.89	67.34	50.63	68.64
	Spring	6.06	9.21	17.10	18.64	18.59	15.07	38.54	16.85	28.58	63.24	44.65	60.75
	Loss	6.74	2.53	+4.53	4.58	0.45	2.93	+7.22	3.00	9.31	4.10	5.98	7.89
Palestine	Fall	8.22	7.44	9.14	8.28	13.23	23.12	18.00	22.41	19.86	34.50	43.08	59.12
	Spring	2.56	9.09	14.59	18.26	29.45	18.28	13.08	15.75	21.95	33.90	54.29	54.82
	Loss	5.66	+1.65	+5.45	+9.98	+16.22	4.84	4.92	6.66	+2.09	0.60	+11.21	4.30
West Salem	Fall	10.04	11.80	16.52	18.61	29.54	20.57	22.05	21.53	27.50	50.70	62.87	64.59
	Spring	7.83	3.62	8.82	30.05	7.52	25.65	34.78	10.84	11.19	72.66	21.98	45.66
	Loss	2.21	8.18	7.70	+11.44	22.02	+5.08	+12.73	10.69	16.31	+21.96	40.89	18.93

parent losses become actual gains of about 100 pounds per acre for the sweet clover plots.

The manure plots gained 27.5 pounds per acre instead of losing 61.86 as the checks did. If the difference came from nitrification of the manure, it offsets the comparison.

This study was conducted during the wettest spring recorded for a great many years. In a normal fall, winter, and spring, greater differences would be found in favor of the sweet clover as a conserver.

SUMMARY

Nitrification of both fall and spring-plowed sweet clover proceeded rapidly and to such an extent on the Joliet Field as to furnish nitrate in excess of the requirements of a large corn crop. The spring-plowed area was in better physical condition and required less labor in preparation than the fall-plowed area. More organic matter was plowed under on the spring-plowed half, which is one of the most important considerations in the initial use of sweet clover. Fall plowing of sweet clover is frequently desirable, but until more information is available as to thorough methods of killing the crop, spring plowing should be the general practice.

The rate of nitrification of sweet clover plowed in the spring, at different dates prior to corn planting, coincided closely with the date of plowing, that is, early plowing gave higher nitrate at an earlier date than later plowing. At both Hartsburg and Toledo, all dates of plowing permitted a rapid nitrification and an accumulation sufficient to meet the needs of much larger crops than were produced. As sweet clover had been grown several times as a green manure on each of these series, a generally higher level of nitrate accumulation than in soils not so treated exists here, and this condition reduced the possibility of larger differences in nitrates resulting from the effect of prolonging the spring growth period.

The date of plowing in the spring should be decided according to the urgency of the need of the soil for active organic matter, as the condition of sweet clover during all the time available for spring plowing ensures its rapid nitrification. The sweet clover on light, sandy, and open textured soils and on those deficient in organic matter should be plowed as late as consistent with good soil preparation for the corn crop. Early plowing of the sweet clover on heavy types, clays, and silts, and on those soils where the crop has grown one or more times, will not materially affect corn production.

Summer-plowed green sweet clover nitrifies rapidly and large amounts of nitrate accumulate, as indicated by the results reported from the study at Bloomington. Large losses result if no protective crop is seeded. Oats and rye proved efficient in converting much nitrate into organic nitrogen and in reducing the amount formed, both of which reduced the losses. The oats were more valuable in reducing losses than the rye, because of their greater fall growth and the fact that they were incorporated with the soil in a dry condition instead of in the green condition.

The handling of sweet clover in this manner is not desirable except in special cases, for equal soil enrichment can be accomplished by using the crop as a green manure, without sacrificing a year to the growing of this crop.

Nitrates concentrate in the surface soil, rising from lower layers. The rise is proved by the fact that it occurred with the moisture content of the surface soils below the point of supporting nitrification. In many cases over 100 pounds of nitrate nitrogen was found in the surface, even in the presence of a crop of 50 to 65 bushels of corn, which was practically produced at this time. Such amounts of nitrate nitrogen should be converted by crops, or by bacteria in order to conserve them for use by succeeding crops. Under farm conditions, weeds in the corn, volunteer grains, and any crop growth on the land in late summer and fall serve to convert much nitrate. If a legume is used, the nitrogen so saved is rapidly and more completely nitrified the following year. Thus, if nitrates are not readily available, use a legume; if nitrates are present in ample amounts, use a grain crop for conserving them.

Two-year rotations of corn, wheat, and sweet clover, or corn, rye, and sweet clover, or corn, barley, and sweet clover seeding sweet clover in the grain, plowing it for corn, and seeding wheat or barley on the corn land, would be efficient from many standpoints especially that of the economical production, utilization, and conservation of nitrate nitrogen. Wheat following oats has been successful in general practice because the moisture, nitrates, and other food have been stored up in the surface during the summer for its fall growth. Rains in the summer do not usually cause serious leaching of plant-food, especially if the oat land is plowed early for wheat.

Studies on thirteen Illinois Experiment Fields during a most disastrous season of rainfall, demonstrated the importance of sweet clover in nitrogen economy. Less nitrate was lost and a large amounts was converted into organic nitrogen by the sweet clover. These results were obtained where sweet clover is grown as a green manure in a four-year rotation.

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INFLUENCE OF FORM, SOIL-ZONE AND FINENESS OF LIME AND MAGNESIA INCORPORATIONS UPON OUTGO OF SULFATES AND NITRATES[1]

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Received for publication December 28, 1925

Among the benefits attributed to the liming of soils is that of accelerating those biological processes which give increased amounts of soluble nitrogen and sulfur for plant growth. Added alkali-earth carbonates, or those derived from CaO or $Ca(OH)_2$ additions, may be decomposed by two processes: They may be dissolved by the carbonated soil water, diffused, and fixed largely in silicate combinations, or they may be decomposed by direct action of biologically-induced nitric and sulfuric acids. The former process depends upon solution and movement of bicarbonates to the surfaces of the acidoids. The latter may be conceived as resulting from the localized generation of the biologically-induced acids and their diffusion to the alkali-earth particles. Under this conception the size of alkali-earth particles and the thoroughness of their dissemination throughout the soil become an important consideration, for even with uniform distribution, the particles of an economic addition are very sparsely spaced in the soil mass. Based on surface exposure, equivalence in immediate reactive values would be approached by use of larger applications of coarser particles and smaller applications of finer material. But, with a constant carbonate equivalence, on an economic basis, a comparison between hydrated lime and fine and coarse limestone separates would be expected to show a superiority for the finer and more widely dispersed materials during a given time.

This contribution is based upon such a comparison. The amounts of sulfates and nitrates leached through an uncropped soil were used as measures of efficiency in promoting biological activities. Variations caused by incorporation of additions in the surface and subsurface zones were also included in the study.

EXPERIMENTAL

The soil used was a brown loam of pH 6.38 in a 1–5 aqueous suspension without preliminary extraction (5). The soil was exposed to natural rain-

[1] From data obtained by means of a research fellowship maintained by the National Lime Association and lysimeter equipment donated by the American Limestone Company of Knoxville.

[2] The results of the first 2 years and those of the third and fourth annual periods were obtained, respectively, by Mr. Hanvey Stanford, Mr. T. D. Hardin, and Dr. R. M. Barnette, all formerly fellowship assistants.

fall for 4 years—May, 1921 to May, 1925. Washed separates of high-calcic and dolomitic limestones were used in comparison with a water-slaked high calcic lime. A constant equivalence of 2,000 pounds of CaO, or 3,570 pounds of $CaCO_3$, per 2,000,000 pounds of soil, moisture-free basis, was used; but the intensity of treatment per zone was actually twice this amount, since the incorporations were made only with either the upper or lower half of the soil stratum. The total nitrogen and sulfur contents of the soil were originally 0.105 per cent and 0.057 per cent, respectively, moisture-free basis. The nitrogen content of the rainfall was not sufficient to be taken into account; but 180.4 pounds of sulfur was brought down during the 4-year period. The details of treatment, of description and illustration of the equipment, and of outgo of calcium and magnesium during the 4-year period have been given in previous contributions (1, 2).

DISCUSSION

Sulfate Outgo

Surface-zone incorporations. The sulfate leachings for the annual and 4-year periods are given in table 1, in which the results are expressed as pounds of S per 2,000,000 pounds of soil. The maximum outgo for the first year was obtained from the hydrated lime. When expressed as $CaSO_4$, the maximum increase in outgo of the first year amounts to 65 pounds, whereas the corresponding maximum for the 4-year period amounts to 88 pounds, or 48.8 per cent of the rainfall increment for the full period. Appreciable total accelerations were induced by the three finer limestone separates and composite, the 40–80-mesh and the 80–200-mesh separates and composite of dolomite. Marked increases were noted more generally during the first year. The 10–20-mesh separates of both limestone and dolomite failed to show any accelerative effect during the first 3 years. As a whole, it might be said that the results from controls and all treatments were quite comparable after the first year.

The total precipitations for the first and second years were 52.52 inches and 52.03 inches, respectively. But with such agreement in rainfall there was a marked decrease in the sulfate outgo both for controls and for treated soils during the second year and a return to a uniformity after that period. This undoubtedly registers the initial abnormality resulting from the thorough mixing and aëration of the soil at the time of placement; but it does not appear whether this was due to actual variation in sulfate production, or to alteration in the retentive capacity of the soil for sulfates.

The beneficial effects of the surface zone incorporations were restricted, in a measure, by the frequent condition of excessive dryness in the upper surface. Furthermore, the generated and leached neutral calcium and magnesium salts may have been partly absorbed during their movement through the un-treated subsurface zone, for it was found (1) that the total amount of calcium

TABLE 1

Sulfate sulfur leached during 4-year period from surface-zone additions of 2000 pounds of CaO and equivalent limestone and dolomite separates

Terms of S per 2,000,000 pounds moisture-free loam soil

TREATMENT	FIRST ANNUAL PERIOD					SECOND ANNUAL PERIOD				THIRD ANNUAL PERIOD				FOURTH ANNUAL PERIOD			TOTAL FOR 4 YEARS	4-YEAR INCREASE IN OUTGO OVER CONTROLS
	May to September	September to January	January to March	March to May	Total	May to December	December to February	February to May	Total	May to September	September to February	February to May	Total	May to December	December to May	Total		
	lbs.	*lbs.*	*lbs.*	*lbs.*	*lbs.*	*lbs.*	*lbs.*	*lbs.*	*lbs.*	*lbs.*	*lbs.*	*lbs.*	*lbs.*	*lbs.*	*lbs.*	*lbs.*	*lbs.*	*lbs.*
Controls	9.5	16.7	17.6	8.1	**51.9**	11.4	11.8	9.3	**32.5**	4.8	12.0	8.5	**25.3**	9.4	16.0	**25.4**	**135.1**	....
$Ca(OH)_2$	15.4	29.2	14.7	7.9	**67.2**	13.8	9.3	8.2	**31.3**	4.1	16.9	6.1	**27.1**	14.6	15.6	**30.2**	**155.8**	+20.7
L. S. 10-20	6.4	18.1	16.5	8.3	**49.3**	12.9	10.4	8.8	**32.1**	3.9	16.0	7.0	**26.9**	12.3	20.6	**32.9**	**141.2**	+ 6.1
L. S. 20-40	6.9	22.1	15.5	7.5	**52.0**	14.0	11.1	8.9	**34.0**	4.5	17.5	7.0	**29.0**	14.8	15.5	**30.3**	**145.3**	+10.2
L. S. 40-80	7.4	26.4	15.6	7.7	**57.1**	14.1	10.8	9.0	**33.9**	4.7	18.2	5.6	**28.5**	15.3	15.9	**31.2**	**150.7**	+15.6
L. S. 80-200	10.1	24.1	17.1	9.2	**60.5**	14.8	10.2	7.6	**32.6**	5.4	17.1	6.0	**28.5**	13.3	15.3	**28.6**	**150.2**	+15.1
L. S. Comp.	6.7	27.9	16.3	8.7	**59.6**	13.7	8.8	8.6	**31.1**	4.6	17.6	6.6	**28.8**	14.2	16.6	**30.8**	**150.3**	+15.2
Dol. 10-20	6.5	17.5	16.2	6.5	**46.7**	11.5	9.3	9.9	**30.7**	3.1	15.6	6.6	**25.3**	11.0	20.1	**31.1**	**133.8**	− 1.3
Dol. 20-40	8.0	20.3	15.3	9.0	**52.6**	11.9	9.8	8.5	**30.2**	3.3	16.5	6.2	**26.0**	13.6	17.9	**31.5**	**140.3**	+ 5.2
Dol. 40-80	7.1	23.4	16.6	8.5	**55.6**	12.3	11.4	10.5	**34.2**	4.1	17.4	6.7	**28.2**	13.8	17.8	**31.6**	**149.6**	+14.5
Dol. 80-200	7.8	26.6	15.3	9.3	**59.0**	12.1	10.6	8.4	**31.1**	4.0	16.3	7.4	**27.7**	13.9	16.6	**30.5**	**148.3**	+13.2
Dol. Comp.	7.7	24.0	14.9	7.3	**53.9**	13.8	11.3	9.9	**35.0**	4.0	17.4	7.2	**28.6**	14.9	17.6	**32.5**	**150.0**	+14.9

TABLE 2

Sulfate sulfur leached during 4-year period from subsurface-zone additions of 2,000 pounds of CaO and equivalent limestone and dolomite separates

Terms of S per 2,000,000 pounds moisture-free loam soil

TREATMENT	FIRST ANNUAL PERIOD					SECOND ANNUAL PERIOD				THIRD ANNUAL PERIOD				FOURTH ANNUAL PERIOD			TOTAL FOR 4 YEARS	4-YEAR INCREASE IN OUTGO OVER CONTROLS
	May to September	September to January	January to March	March to May	Total	May to December	December to February	February to May	Total	May to September	September to February	February to May	Total	May to December	December to May	Total		
	lbs.	*lbs.*	*lbs.*	*lbs.*	*lbs.*	*lbs.*	*lbs.*	*lbs.*	*lbs.*	*lbs.*	*lbs.*	*lbs.*	*lbs.*	*lbs.*	*lbs.*	*lbs.*	*lbs.*	*lbs.*
Controls	9.5	16.7	17.6	8.1	**51.9**	11.4	11.8	9.3	**32.5**	4.8	11.9	8.5	**25.2**	9.4	16.0	**25.4**	**135.1**	....
$Ca(OH)_2$	28.9	22.8	9.6	5.9	**67.2**	13.2	7.8	6.1	**27.1**	5.7	12.7	6.7	**25.1**	12.6	16.5	**29.1**	**148.5**	+13.4
L. S. 10–20	9.8	19.9	14.6	10.3	**54.6**	13.7	9.3	9.4	**32.4**	6.7	14.2	7.2	**28.1**	13.0	13.6	**26.6**	**141.7**	+ 6.6
L. S. 20–40	12.4	26.1	13.3	10.4	**62.2**	16.4	10.3	8.6	**35.3**	5.9	15.3	7.5	**28.7**	14.4	17.8	**32.2**	**158.4**	+23.3
L. S. 40–80	19.5	25.0	11.2	6.0	**61.7**	15.0	8.8	6.8	**30.6**	5.9	13.2	7.4	**26.5**	12.8	20.1	**32.9**	**151.7**	+16.6
L. S. 80–200	23.1	24.8	9.7	6.1	**63.7**	12.6	7.4	7.4	**27.4**	4.8	12.1	7.0	**23.9**	11.5	14.9	**26.4**	**141.4**	+ 6.3
L. S. Comp.	16.7	25.2	11.9	7.6	**61.4**	14.9	8.6	7.9	**31.4**	6.3	13.9	6.3	**26.5**	12.9	17.8	**30.7**	**150.0**	+14.9
Dol. 10–20	8.3	18.5	15.4	7.7	**49.9**	16.4	8.4	9.0	**33.8**	4.2	14.3	6.9	**25.4**	10.6	17.2	**27.8**	**136.9**	+ 1.8
Dol. 20–40	8.2	23.9	13.3	7.4	**52.8**	15.7	6.9	7.9	**30.5**	4.1	14.5	7.4	**26.0**	12.7	16.3	**29.0**	**138.3**	+ 3.2
Dol. 40–80	11.8	27.4	12.4	7.5	**59.1**	15.7	9.7	8.2	**33.6**	6.6	14.6	10.5	**31.7**	12.9	17.1	**30.0**	**154.4**	+19.3
Dol. 80–200	16.3	26.3	11.6	6.3	**60.5**	15.0	8.2	6.2	**29.4**	6.6	12.6	7.1	**26.3**	12.0	15.7	**27.7**	**143.9**	+ 8.8
Dol. Comp.	12.8	25.6	11.8	6.8	**56.9**	15.0	10.4	8.7	**34.1**	5.4	15.8	8.6	**29.8**	13.8	19.2	**33.0**	**153.8**	+18.7

and magnesium which passed out from the surface zone was materially reduced in that way. To offset this absorption exerted by the lower zone, however, some beneficial effect from bicarbonates carried down to the untreated subsurface zone from the surface zone, may be expected.

Although the sulfur outgo from every treatment, save 10–20-mesh dolomite, was greater than that from the untreated soil, total outgo was in no case equal to the sulfate sulfur brought down by rain waters.

Subsurface-zone incorporations. The tanks which received subsurface-zone additions (table 2) may be regarded as having yielded a constant amount of sulfates from the untreated surface zone. The leaching variations induced by additions to the lower zone may therefore be considered as due solely to activities within that zone.

Again, as in the case of the surface-zone additions, the hydrated lime produced the largest outgo during the first year, but not thereafter. During the first year, 10 of the 11 additions yielded sulfates in excess of the outgo from the controls. During the 4-year period 3 of the limestone additions and 2 of the dolomite separates caused sulfate losses in excess of the outgo from the hydrated lime. Previous results (2) demonstrated the fact that all limestone separates were much more extensively, and presumably more rapidly, disintegrated in the lower zone. As this tended to minimize the influence of variations in size of particles in the lower zone, no consistent differences appear. The lime treatment, two of the limestone, and two of the dolomite additions gave losses less than those from corresponding surface-zone incorporations, although the reverse was true for 3 of the limestone and 3 of the dolomite additions; but in 4 cases the differences were small.

As in the case of the surface-zone additions all treatments, save 10–20-mesh dolomite, gave appreciable accelerations in sulfate outgo; but, again in no case did the total for 4 years equal the rainfall supply of sulfates.

Nitrate Outgo

Surface-zone incorporations. With the exception of the 10–20-mesh limestone separate, all additions resulted in nitrate leachings in excess of the outgo from the control for the first year (table 3). During the same period the two finer limestone separates and the hydrated lime yielded the largest increases, and the finer limestone separates were more accelerative than were the corresponding dolomite separates. In the second year each limestone separate was more accelerative than its corresponding dolomite separate in promoting nitrate outgo. During this period of each of four limestone separates, three of the dolomite separates and their composite gave losses greater than the outgo from hydrated lime. During the third year the hydrated lime yielded less of nitrates than did the control, but increased outgo was obtained from all separates and both composites. With the exception of the dolomite composite the same was true also for the fourth year.

TABLE 3

Nitrate N leached during 4-year period from surface-zone additions of 2,000 pounds of CaO and equivalent limestone and dolomite separates

Terms of N per 2,000,000 pounds of moisture-free loam soil.

TREATMENT	FIRST ANNUAL PERIOD					SECOND ANNUAL PERIOD				THIRD ANNUAL PERIOD				FOURTH ANNUAL PERIOD			TOTAL FOR 4 YEARS	4-YEAR INCREASE IN OUTGO OVER CONTROLS
	May to September	September to January	January to March	March to May	Total	May to December	December to February	February to May	Total	May to September	September to February	February to May	Total	May to December	December to May	Total		
	lbs.	*lbs.*	*lbs.*	*lbs.*	*lbs.*	*lbs.*	*lbs.*	*lbs.*	*lbs.*	*lbs.*	*lbs.*	*lbs.*	*lbs.*	*lbs.*	*lbs.*	*lbs.*	*lbs.*	*lbs.*
Controls	20.8	32.1	3.3	6.9	**63.1**	32.4	2.3	2.4	**37.1**	21.1	11.2	1.8	**34.1**	29.6	5.1	**34.7**	**169.0**	....
$Ca(OH)_2$	28.9	47.6	4.9	6.7	**88.1**	41.7	3.5	1.6	**46.8**	20.9	4.1	3.3	**28.3**	29.6	2.3	**31.9**	**195.1**	+26.1
L. S. 10–20	22.4	30.4	4.3	4.9	**62.0**	41.2	1.3	1.6	**44.1**	21.9	11.8	3.2	**36.9**	33.6	4.4	**38.0**	**181.0**	+12.0
L. S. 20–40	25.9	41.9	3.7	6.1	**77.6**	51.4	4.3	2.9	**58.6**	28.8	13.5	3.3	**45.6**	38.5	6.3	**44.8**	**226.6**	+57.6
L. S. 40–80	36.7	44.6	3.9	7.1	**92.3**	59.9	3.4	3.6	**66.9**	28.1	11.6	2.8	**42.5**	37.4	5.0	**42.4**	**244.1**	+75.1
L. S. 80–200	34.1	53.2	2.7	4.2	**94.2**	54.2	3.2	3.4	**60.8**	32.0	12.3	3.3	**47.6**	30.7	5.0	**35.7**	**238.3**	+69.3
L. S. Comp.	26.6	37.9	4.6	5.8	**74.9**	22.5	2.5	1.0	**26.0**	24.7	10.3	3.2	**38.2**	32.6	2.7	**35.3**	**174.4**	+ 5.4
Dol. 10–20	23.9	38.8	2.6	3.2	**68.5**	30.9	3.6	2.4	**36.9**	22.6	19.6	3.4	**45.6**	36.1	5.3	**41.4**	**192.4**	+23.4
Dol. 20–40	26.4	39.2	2.8	5.3	**73.7**	43.3	3.5	2.5	**49.3**	27.2	14.9	3.4	**45.5**	36.6	6.0	**42.6**	**211.1**	+42.1
Dol. 40–80	21.7	41.9	3.4	3.9	**70.9**	47.0	2.9	1.9	**51.8**	25.9	16.8	3.5	**46.2**	33.6	5.7	**39.3**	**208.2**	+39.2
Dol. 80–200	29.1	44.7	3.4	2.8	**80.0**	49.7	2.9	2.7	**55.3**	32.9	17.9	4.0	**54.8**	31.3	5.8	**37.1**	**227.2**	+58.2
Dol. Comp.	24.7	41.0	3.4	4.5	**73.6**	48.4	3.9	2.6	**54.9**	27.4	15.9	3.3	**46.6**	29.4	4.8	**34.2**	**209.3**	+40.3

TABLE 4

Nitrate N leached during 4-year period from subsurface-zone additions of 2,000 pounds of CaO and equivalent limestone and dolomite separates

Terms of N per 2,000,000 pounds of moisture-free loam soil

TREATMENT	FIRST ANNUAL PERIOD					SECOND ANNUAL PERIOD				THIRD ANNUAL PERIOD				FOURTH ANNUAL PERIOD			TOTAL FOR 4 YEARS	4-YEAR INCREASE IN OUTGO OVER CONTROLS
	May to September	September to January	January to March	March to May	Total	May to December	December to February	February to May	Total	May to September	September to February	February to May	Total	May to December	December to May	Total		
	lbs.	*lbs.*	*lbs.*	*lbs.*	*lbs.*	*lbs.*	*lbs.*	*lbs.*	*lbs.*	*lbs.*	*lbs.*	*lbs.*	*lbs.*	*lbs.*	*lbs.*	*lbs.*	*lbs*	*lbs.*
Controls	20.8	32.1	3.3	6.9	**63.1**	32.4	2.3	2.4	**37.1**	21.1	11.2	1.8	**34.1**	29.6	5.1	**34.7**	**169.0**	....
$Ca(OH)_2$	38.9	35.7	3.6	6.4	**84.6**	26.7	1.4	0.8	**28.9**	24.9	3.1	3.2	**31.2**	26.6	2.3	**28.9**	**173.6**	+ 4.6
L. S. 10–20	19.4	35.8	5.4	7.4	**68.0**	47.0	3.1	1.2	**51.3**	22.7	12.2	3.1	**38.0**	33.8	5.0	**38.8**	**196.1**	+27.1
L. S. 20–40	36.9	43.8	3.4	5.3	**89.4**	50.0	3.9	3.1	**57.0**	25.0	10.6	2.9	**38.5**	35.1	4.9	**40.0**	**224.9**	+55.9
L. S. 40–80	30.8	48.8	4.6	6.2	**90.4**	49.3	4.1	2.7	**56.1**	26.6	8.3	3.6	**38.5**	29.3	5.0	**34.3**	**219.3**	+50.3
L. S. 80–200	30.0	48.7	3.5	3.5	**85.7**	35.3	2.5	1.5	**39.3**	24.4	5.8	3.4	**33.6**	30.4	5.2	**35.6**	**194.2**	+25.2
L. S. Comp.	31.0	31.0	4.0	4.8	**70.8**	35.7	1.4	1.1	**38.2**	21.5	5.8	3.1	**30.4**	26.5	3.4	**29.9**	**169.3**	+ 0.3
Dol. 10–20	32.6	36.2	2.6	5.0	**76.4**	41.1	3.3	1.7	**46.1**	29.4	13.5	3.6	**46.5**	24.7	5.2	**29.9**	**198.9**	+29.9
Dol. 20–40	26.3	36.5	3.3	5.3	**71.4**	50.3	2.7	2.1	**55.1**	23.4	17.9	4.0	**45.3**	32.4	5.0	**37.4**	**209.2**	+40.2
Dol. 40–80	34.2	37.9	3.1	5.6	**80.8**	39.2	5.5	3.4	**48.1**	32.2	14.9	5.2	**52.3**	25.9	5.1	**31.0**	**212.2**	+43.2
Dol. 80–200	32.8	46.3	2.9	5.3	**87.3**	50.0	2.2	2.8	**55.0**	37.0	14.9	4.1	**56.0**	29.2	5.3	**34.5**	**232.8**	+63.8
Dol. Comp.	29.6	40.9	2.4	6.1	**79.0**	48.6	4.3	2.5	**54.9**	29.4	17.0	3.4	**49.8**	32.2	6.0	**38.2**	**221.9**	+52.9

For the 4-year period the 20–40-, 40–80-, and 80–200-mesh separates of both limestone and dolomite gave nitrate losses in excess of the outgo from the hydrated lime treatment. The differences between the influence of 10–20-mesh separate and that of the finer separates are quite marked for both limestone and dolomite. The finer separates of limestone proved more accelerative than the corresponding dolomite separates; but for some reason unexplained, the reverse was true of the composites. As was the case with the sulfates, there was a distinct decrease after the first year; but, in general, the enhanced outgo was continuous throughout the 4-year period.

With the exception of the first year, the losses from May to December constituted the larger fractions of the several annual losses. In this respect nitrification differed from sulfofication, since the generation of sulfates was evenly distributed throughout the year.

Subsurface-zone incorporations. The hydrated lime addition gave an enhanced outgo, approximately the same as that from the surface incorporation during the first annual period, but the reverse was true during the succeeding three years, so that, differing from the same addition to the surface zone, the total outgo was only slightly greater than that from the controls (table 4).

The correlation between nitrification and disintegration of separates may be seen more readily by reference to the determinations of residual carbonates, as given in a preceding contribution (2). All of the limestone and dolomite additions caused increased nitrate outgo during the first year, but the influence of fineness was not so apparent as in the upper-zone additions. In general the same may be said of the results for the third and fourth years. In the totals there was found the same superiority of dolomite composite over the limestone composite noted in the surface-zone incorporations. Peculiarly, the relation between increasing outgo and progressive fineness was more definitely shown in the case of the more slowly disintegrated dolomite than in the case of the more rapidly disintegrated limestone. The 80–200-mesh limestone fell behind the 40–80-mesh separate during the first 3 years and the two were practically equivalent for the fourth year, so that the 4-year outgo from the finer separate was decidedly less.

In agreement with the sulfate outgo, the 4-year nitrate yield from the hydrated lime addition was much less than that from the same incorporation in the surface zone. The lower-zone addition could hardly affect the overlying untreated zone. The same addition in the upper zone, however, exerted its effect not only there, but also in the lower zone because of the bicarbonates leached to it. The three finer high-calcic limestone separates had the same effect, but the reverse was true of the 10–20-mesh separate which had been more extensively disintegrated in the lower zone (2). Neither surface-zone, nor subsurface-zone incorporations of the limestone composite evidenced appreciable effect upon nitrate outgo; but both incorporations of dolomite exerted a distinct effect, the lower-zone addition having been the

more active. No large or consistent differences appeared to be attributable to the several dolomite separates as influenced by zone of incorporation.

SUMMARY

The maximum enhancements in average annual leachings of sulfur and nitrogen from the uncropped soil were only 5.8 pounds and 18.8 pounds, respectively. Those amounts would probably have been still further reduced had non-legumes been grown during the 4-year period. Judged by its pH value, the soil is not to be considered as strongly acid, but it responds to moderate liming in the field and it has shown capacity to disintegrate twice as much $CaCO_3$ (2) as that supplied by the 3570-lb. equivalence from CaO, and finely divided limestone and dolomite. In the light of those characteristics, certain of the sulfate and nitrate findings are consistent while others are not, in spite of the definite correlation between the disintegrations (2) and the calcium-magnesium outgo (1) as influenced by form, fineness and zone-of-incorporation. In a sense, the sulfate results may be considered as showing the influence of the additions upon the soil's tendency to retain sulfates, since in no case was the sulfate outgo equivalent to the rainfall increment of sulfate sulfur.

In the surface incorporation group $Ca(OH)_2$ was most accelerative upon sulfate outgo. The finer separates of limestone and dolomite were comparable and both were more potent than the corresponding coarser materials, the greatest differences having occurred during the first year. In nitrate production the coarser separates had less effect than the finer separates and those in turn caused nitrate leachings in excess of those from the hydrated lime. Each of the finer limestone separates was more active than its corresponding dolomite separate, but the reverse was true of the 10–20-mesh and composite additions.

In the subsurface addition group the influence of form and availability, governed by fineness, was not so consistent in producing acceleration of sulfate outgo. In nitrate losses, 9 of the 10 limestone and dolomite separates gave leachings in excess of the outgo from $Ca(OH)_2$. In this zone of greater carbonate disintegration, the influence of increase in surface of separates was not so marked, nor was the relationship between limestone and dolomite so well established.

As a whole, excluding the 10–20-mesh separates, it appears that neither degree of fineness of 2000-pound CaO equivalences of $Ca(OH)_2$, of limestone, and of dolomite, nor depth of incorporation was uniformly consistent in its influence upon the total losses of sulfates and nitrates from this particular soil during the 4-year period, under the prevailing climatic conditions.

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SOME SOIL AND PLANT RELATIONSHIPS

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Received for publication January 23, 1926

It has been stated previously that water is one of the best indices of several soil characteristics, such as texture, structure, colloidal content, and activation of surfaces (1). A study of the moisture relationships of plants grown under different conditions appears to be profitable. Results reported by McCool and Millar (2) from the use of the dilatometer method raised the question as to the effect of the composition of soil solution upon the amount of easily freezable water in plant tissue. Later the question was raised with respect to the use of the heat of wetting method in studying the moisture relationships of soils and plants. Accordingly samples of alfalfa were taken at different periods during the growing seasons of 1924 and 1925 from certain plots of one of our fertility fields. In addition samples of other crops growing on differently treated muck and mineral soils were collected.

THE EFFECT OF DIFFERENT TREATMENTS ON HEAT OF WETTING

Samples of alfalfa were exposed 24 hours to four different temperatures and the calories per gram liberated upon wetting were determined. The results obtained are presented in table 1.

The data show that some heat is evolved when this plant tissue is brought into contact with water after it has been exposed to a temperature of 22°C.; about twice this amount, after it has been held at a temperature of 60°C.; four times as much, in case of the 90°C. exposure; and a relatively slight increase in amount, with the further 10°C. rise of temperature.

Samples of alfalfa, soybeans and clover were leached until the freezing point depressions, as determined by the Beckmann thermometer, were very low. The samples were then dried in the oven at 96°C. The heat of wetting determinations were made upon these samples and also upon samples that had not been leached. According to the data in table 2 the heat of wetting of these plant materials increases slightly upon leaching. It appears that the heat of wetting is due in the main to the insoluble substances—probably colloidal in nature—in the tissue. When leached, the proportion of these in a given amount of material increases. This condition probably brings about increases in the heat of wetting.

HEAT OF WETTING OF DIFFERENT MATERIALS

Before taking up the effects of different kinds of soils and their treatment on the water relationships, the heat of wetting of a number of plants, leaves, roots, and seeds, and commercial corn starch was determined. The calories of heat given off per gram of each of the materials employed are given in table 3.

It is to be noted that the samples of corn starch yielded the highest heat of wetting, and that of the seeds, the wheat, rye, and corn are next in order, with Canadian field pea, field bean, and alfalfa slightly lower. Other materials that yielded similar results were soybean, sweet clover, white clover, and red clover. Of the remaining materials studied, the leaves of peach and apple trees give strikingly low results.

TABLE 1

The effect of temperature on heat of wetting of alfalfa

TEMPERATURE	HEAT OF WETTING
°C.	*calories per gram*
22	3.85
60	7.85
90	15.03
100	16.05

TABLE 2

The effect of leaching upon the heat of wetting

KIND OF PLANT	UNLEACHED	LEACHED
	calories	*calories*
Alfalfa	15.31	17.97
Red clover	15.80	17.62
Soybeans	17.70	19.81

THE EFFECT OF FERTILIZATION ON WATER RELATIONSHIPS OF PLANTS

Since the indications are that the nature of the plant materials affects the heat of wetting somewhat, it was considered advisable to determine whether the fertilization of soils affects the water relationships of the crops grown on them. On August 10, samples of leaves were taken from sugar beets, chicory, and white clover growing on differently fertilized muck plots; and on July 28, from soybeans growing on mineral soil. Samples of parsnip roots, turnip roots, table beet roots, and celery leaves were collected on November 5. The essential data are given in table 4.

The results show that the leaves of the plants grown on the unfertilized muck soil—notably sugar beet, chicory, celery, and white clover—have a higher heat of wetting than those taken from the differently fertilized plots; whereas the soybean leaves of plants grown on mineral soil give similar but somewhat

less striking results. Negative results were obtained from alfalfa and sweet clover tops and also from beet, parsnip, and turnip roots.

Although fertilization did not affect the amount of heat evolved by alfalfa when moistened, it is apparent that the time of cutting and consequently the

TABLE 3

The heat of wetting of different materials

MATERIAL	HEAT OF WETTING
	calories per gram
Cornstarch	20.1
Wheat	18.8
Rye	18.6
Corn grain	17.8
Field pea	17.3
Field bean	15.6
Alfalfa seeds	15.1
Soybean leaves	17.9
Sweet clover tops	16.1
White clover tops	15.8
Red clover leaves	16.0
Alfalfa roots	14.0
Turnip roots	9.2
Maple leaves	15.3
Beech leaves	13.8
Oak leaves	13.7
Cherry leaves	13.6
Mature Kentucky Bluegrass	15.2
Young Kentucky Bluegrass	13.4
Apple leaves	10.1
Peach leaves	8.9
Celery leaves	11.1
Parsnip roots	9.7

TABLE 4

The effect of fertilization on the heat of wetting

MATERIAL	TREATMENT				
	O	K	P	PK	NPK
Sugar beet leaves	9.7	5.5	7.3	3.8	....
Chicory leaves	16.9	15.8	18.4	12.5	....
Celery leaves	11.4		10.6	10.4	9.2
Soybean leaves	17.1		15.8	16.8	
White clover	17.2			15.9	13.7

composition of the plant does affect it. Grimm alfalfa sampled on May 21, 1924 gave a heat of wetting of 14.2 calories per gram, whereas on June 26 it was 17.7 calories. Similar results were obtained with Cossack and the common variety of alfalfa and also with Kentucky bluegrass.

It would be interesting to determine whether there is any relationship between soil fertilization and heat of wetting and the loss of water from plants when harvested. It is probable that the concentration of the cell sap, as affected by the treatment afforded the soil, plays an important rôle in such losses, perhaps more so than the colloids present as indicated by the heat of wetting method. M. F. Mason[1] determined the amount of easily freezable water in moistened leaves of white clover and soybean grown on fertilized and unfertilized soil and found it to be greater in those taken from the unfertilized areas. On the other hand when these were leached with distilled water the results obtained were reversed.

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[1] Unpublished data, this laboratory.

SOME EFFECTS OF MULCHING PAPER ON HAWAIIAN SOILS

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Received for publication January 25, 1926

INTRODUCTION

The use of mulching paper upon Hawaiian crops was first started by C. F. Eckart, Manager of Olaa Sugar Company, at Olaa, Hawaii, in the year 1914. The lands of the Olaa Sugar Company are located largely in the windward section of the Island of Hawaii, in a region of high annual rainfall. The average yearly precipitation ranges from 150 to 200 inches on most of the plantation fields. This rainfall tends to cause a heavy growth of weeds, so that weed control was originally one of the heaviest expenses of this plantation.

Eckart first applied mulching paper for weed control to the "kua-kua" or portion of the cane furrow which lies between the actual rows of cane. This middle part of the cane furrow is ordinarily kept clear from weeds by animal or hand cultivation until the cane is large enough to shade the ground and prevent weed development. This use of mulching paper proved effective in reducing weed growth in the middle portion of the furrow, but left the weeds a chance to develop around the cane stalks. Here weeds could only be removed by hand hoeing.

In 1916 the process was modified by Eckart, and "row mulching" was introduced. In this method of using the paper mulch, a light weight tar or asphalt impregnated paper was spread directly over the row of seed cane or harvested stubble. When the young cane shoots first appeared they were extremely sharp and those that grew upright readily pierced the mulching paper. Some of the shoots that grew diagonally, however, would commence to unfold under the paper and after four to six weeks it was necessary to slit the mulching paper. By this time practically all the weeds under the paper had been killed, whereas the cane shoots were unharmed.

The mulching paper used at Olaa was 3 feet wide. This left an uncovered space in the center of the cane row. The cane trash was collected into this space before the paper was laid and served as an effective mulch to keep down most of the weeds. As the labor required in weed control is greatly reduced by the use of the paper mulch, it is now the standard plantation practice at Olaa Sugar Company. An ideal paper for use on sugar cane is manufactured at Olaa from bagasse and wood pulp.

It was observed in the early work at Olaa that the paper mulch appeared to exert some other effect upon the crop, in addition to preventing injury from weed growth. Paper mulched plots made a noticeably better growth than adjoining plots which were kept equally free from weeds. This difference was especially noticeable during the early period of growth before the cane had "closed in" and completely shaded the soil. Eckart attributed this to added soil warmth and to moisture conservation due to the paper. Larsen (2) reported that the soil under the paper mulch was from 3 to 6° higher in temperature than bare soil.

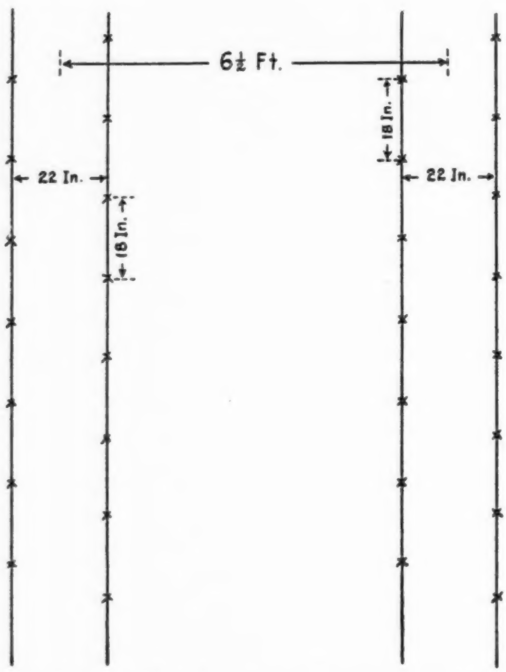

FIG. 1. DOUBLE-ROW SCHEME FOR PLANTING PINEAPPLES

The favorable effect upon the growth of sugar cane suggested the trial of the paper mulch upon the pineapple crop. Trial plantings were made by the Hawaiian Pineapple Company in 1919 and 1920. The growth obtained under the paper mulch was notably better than that made by adjacent unmulched plots. As a result of these experiments the Hawaiian Pineapple Company in 1922 purchased Echart's patent rights for the use of mulching paper upon the pineapple crop in Hawaii. At the present time the great majority of the pineapples grown in Hawaii are planted in mulching paper.

Because of the widespread use of mulching paper with pineapples, it appeared desirable to obtain more detailed information as to the effect of the paper mulch upon the soil. The experiments reported here were carried out as part of the chemical work performed by this Experiment Station for the Association of Hawaiian Pineapple Canners during the years 1921 to 1924 inclusive.

In the Hawaiian Islands pineapples are ordinarily planted in a 2-row system, which is indicated in figure 1. The distance between the pairs of rows is usually $6\frac{1}{2}$ feet from center to center. The individual rows of each pair are commonly 22 inches apart and the plants are set in a staggered effect 18 inches apart in the row. The usual procedure is to apply a mixed fertilizer at the rate of 500 to 750 pounds per acre on the line of the row before laying the paper. The method of laying the paper is illustrated in plate 1, figure 1. The plants are then inserted through the paper so that a new planted field will appear as in plate 1, figure 2.

With the pineapple crop it is considered desirable to have the mulching paper last as long as possible. The paper used is therefore a tar or asphalt impregnated and coated paper similar to a light or medium grade of building paper. This type of material will ordinarily last until one or more ratoon crops have been harvested.[1] Before the introduction of the paper mulch it was unusual to obtain more than two ratoon crops, but it is now hoped that the larger and more vigorous plants grown under the paper mulch may ratoon for a larger period of time.

EXPERIMENTAL

The studies carried out in this investigation have been concerned with determining the effect of the paper mulch upon soil temperature, soil moisture, and ammonification and nitrification of the soil. All of these observations were made under field conditions.

Effect of paper mulch upon soil temperature

The work on soil temperature has extended over a period of more than two years and has consisted of determining the temperature of the bare soil and of comparison with paper mulched plots. During the first part of the work, no pineapple plants were grown, as it was desired to find the effect of the mulching paper on the soil with the varying weather conditions that occur at different seasons of the year. After temperatures in mulched and unmulched soil were followed throughout an entire season, pineapple plants were put in and the observations were continued.

The temperatures were recorded by combined soil and air thermographs.

[1] It may be explained that on the pineapple plantations in Hawaii it is customary to speak of the first crop of pineapples produced in about two years after planting as the "plant crop." The successive crops of fruit produced each year after the plants come in bearing are known as the first, second or third ratoons.

Both Julien P. Friez and J. Richard instruments were used in the work. The soil elements were buried to a depth of 4 inches below the surface. The reading of the soil graphs was checked by placing accurately standardized glass thermometers alongside the soil elements, and reading these thermometers at short intervals until the thermographs and thermometers were in close agreement. After the instruments were in good adjustment, it was found sufficient to check the soil and air elements against accurate thermometers at periods of one or two days.[2]

The data obtained in these temperature studies were so voluminous that it appeared to be feasible to select only certain typical weekly periods to exemplify the changes in soil temperature caused by the paper mulch. Table 1 gives such a weekly record obtained at the Makiki plot of this Experiment Station located in Honolulu. The period was March 5 to 12, 1923, before the recording instruments were transferred to Wahiawa. In this period of the spring, the weather was very variable. It was found immediately that the effect of the paper mulch varied with the weather conditions. During clear, bright weather at this time of the year, the temperature of the soil under paper was generally about 4 to 6°F. warmer, during the middle of the day and afternoon, than the unmulched soil. The temperature of the mulched soil continued to be higher than that of the unmulched plots, even in the night and early morning, though the difference decreased during this night period.

The influence of rainfall was noted early, for rain fell on several days during the period covered in table 1. The rain decreased the difference between the bare soil and the paper mulched plots. In fact it was found later that for a short time after heavy rains the bare soil might be warmer than the soil under the paper mulch. Further work at the Makiki station dealt with the effect of shade. A lath screen was erected over the mulched and unmulched plots and it was found that the effect of the paper mulch on the soil temperature varied directly with the exposure to the sun's rays. When the soil was either half or more shaded, the effect of the paper mulch upon the soil temperature was greatly reduced.

The work was then transferred to Wahiawa in a typical pineapple district where the experimental plots were located at the Experiment Station of the Hawaiian Pineapple Canners' Association. The work upon bare plots with and without paper was continued in order to discover the effect of the paper mulch at different seasons of the year.

During the early summer, the differences were of somewhat the same order as those previously observed in Honolulu. A typical period during late May is given in table 2. As the season progressed and the maximum air tempera-

[2] The major portion of the soil temperature records was made at the Experiment Station of the Association of Hawaiian Pineapple Canners, located at Wahiawa, Oahu. The collection of the records was made by the agricultural department of that station. The photographs illustrating this article were furnished us by H. L. Denison, Agriculturist of the Pineapple station.

TABLE 1

Soil temperatures in ordinary cane furrows

Makiki Station, Hawaiian Sugar Planters' Association, March 5 to 12, 1923

DATE	HOUR	WEATHER	TEMPERATURE OF AIR	TEMPERATURE OF SOIL		DIFFERENCE DUE TO PAPER
				No paper	Under paper	
			°F.	°F.	°F.	°F.
March 5	12 noon	Fair	80	77	80	3
	2 p.m.		80	81	87	6
	4 p.m.		78	81	87	6
	6 p.m.		76	81	86	5
	8 p.m.		74	79	83	4
	10 p.m.		73	77	81	4
	12 midnight		73	75	80	5
March 6	2 a.m.	Cloudy during part of day	73	73	78	5
	4 a.m.		71	73	77	4
	6 a.m.		72	71	76	5
	8 a.m.		73	71	75	4
	10 a.m.		75	72	76	4
	12 noon		76	74	79	5
	2 p.m.		77	78	83	5
	4 p.m.		76	81	85	4
	6 p.m.		73	81	83	2
	8 p.m.		72	77	81	4
	10 p.m.		71	75	79	4
	12 midnight		70	73	78	5
March 7	2 a.m.	Cloudy during part of day	70	73	76	3
	4 a.m.		71	73	75	2
	6 a.m.		71	71	75	4
	8 a.m.		72	71	74	3
	10 a.m.		75	71	75	4
	12 noon		76	73	76	3
	2 p.m.		76	75	79	4
	4 p.m.		73	77	79	2
	6 p.m.		71	75	78	3
	8 p.m.		68	73	76	3
	10 p.m.		68	72	74	2
	12 midnight		68	71	73	2
March 8	2 a.m.		69	71	73	2
	4 a.m.		69	71	72	1
	6 a.m.	Cloudy and showers	69	70	69	−1
	8 a.m.		69	69	69	0
	10 a.m.		71	69	71	2
	12 noon		70	70	78	8
	2 p.m.		75	73	83	10
	4 p.m.		73	75	82	7
	6 p.m.		72	75	80	5
	8 p.m.		70	73	68	−5
	10 p.m.		71	72	69	−3
	12 midnight		71	71	70	−1

TABLE 1—*Continued*

DATE	HOUR	WEATHER	TEMPERATURE OF AIR	TEMPERATURE OF SOIL		DIFFERENCE DUE TO PAPER
				No paper	Under paper	
			°F.	°F.	°F.	°F.
March 9	2 a.m.		70	70	70	0
	4 a.m.		70	70	70	0
	6 a.m.	Cloudy and	69	69	68	−1
	8 a.m.	rain	71	68	68	0
	10 a.m.		74	69	70	1
	12 noon		71	70	72	2
	2 p.m.		71	71	72	1
	4 p.m.		74	72	73	1
	6 p.m.		71	72	72	0
	8 p.m.		70	71	71	0
	10 p.m.		68	70	71	1
	12 midnight		68	69	70	1
March 10	2 a.m.		67	69	68	−1
	4 a.m.		69	68	68	0
	6 a.m.		69	67	68	1
	8 a.m.	Part cloudy	70	67	68	1
	10 a.m.		73	67	69	2
	12 noon		76	68	72	4
	2 p.m.		76	71	76	5
	4 p.m.		75	74	79	5
	6 p.m.		73	76	79	3
	8 p.m.		69	75	76	1
	10 p.m.		68	73	74	1
	12 midnight		68	72	73	1
March 11	2 a.m.		67	70	71	1
	4 a.m.		67	70	70	0
	6 a.m.		67	69	70	1
	8 a.m.	Fair	67	68	70	2
	10 a.m.		71	68	72	4
	12 noon		78	69	76	7
	2 p.m.		77	72	81	9
	4 p.m.		77	75	83	8
	6 p.m.		73	79	81	2
	8 p.m.		69	79	78	−1
	10 p.m.		67	76	76	0
	12 midnight	Showers	66	73	75	2
March 12	2 a.m.		62	73	73	0
	4 a.m.		60	71	72	1
	6 a.m.		60	70	71	1
	8 a.m.		76	68	70	2
	10 a.m.		78	71	72	1
	12 noon		79	73	76	3
	2 p.m.		78	79	82	3
	4 p.m.		77	79	84	5
	6 p.m.		74	77	83	6
	8 p.m.		68	74	81	7
	10 p.m.		65	72	78	6
	12 midnight		62	70	76	6

TABLE 2

Soil temperatures at Wahiawa—early summer, May 21 to 28, 1923

DATE	HOUR	WEATHER	TEMPERATURE OF AIR	TEMPERATURE OF BARE SOIL	TEMPERATURE OF SOIL UNDER PAPER	DIFFERENCE DUE TO PAPER
			°F.	°F.	°F.	°F.
May 21	2 p.m.		81	82	88	6
	4 p.m.		78	83	88	5
	6 p.m.	Clear	74	81	85	4
	8 p.m.		71	78	82	4
	10 p.m.		70	76	80	4
	12 midnight		69	74	77	3
May 22	2 a.m.		69	73	75	2
	4 a.m.		68	72	74	2
	6 a.m.		66	71	72	1
	8 a.m.		75	72	73	1
	10 a.m.		80	74	78	4
	12 noon	Clear	82	80	88	8
	2 p.m.		83	85	90	5
	4 p.m.		80	85	89	4
	6 p.m.		76	83	87	4
	8 p.m.		72	81	84	3
	10 p.m.		72	78	82	4
	12 midnight		70	76	79	3
May 23	2 a.m.		70	75	77	2
	4 a.m.	Clear	69	74	76	2
	6 a.m.		69	73	75	2
	8 a.m.		75	73	75	2
	10 a.m.		80	74	82	8
	12 noon		82	77	88	11
	2 p.m.	Clear	82	83	90	7
	4 p.m.		78	84	90	6
	6 p.m.		75	83	87	4
	8 p.m.		71	81	83	2
	10 p.m.		70	78	81	3
	12 midnight		70	76	79	3
May 24	2 a.m.		70	74	77	3
	4 a.m.		69	73	76	3
	6 a.m.		70	73	75	2
	8 a.m.		77	72	75	3
	10 a.m.	Clear	80	73	79	6
	12 noon		80	75	83	8
	2 p.m.		78	78	85	7
	4 p.m.		75	79	83	4
	6 p.m.		72	79	81	2
	8 p.m.		71	77	78	1
	10 p.m.		69	75	76	1
	12 midnight	Showers	70	74	74	0
May 25	2 a.m.		71	72	73	1
	4 a.m.		69	71	72	1
	6 a.m.		69	70	71	1

TABLE 2—*Continued*

DATE	HOUR	WEATHER	TEMPERATURE OF AIR	TEMPERATURE OF BARE SOIL	TEMPERATURE OF SOIL UNDER PAPER	DIFFERENCE DUE TO PAPER
			°F.	°F.	°F.	°F.
May 25	8 a.m.		72	69	72	3
	10 a.m.		73	70	72	2
	12 noon		74	73	75	2
	2 p.m.		75	75	78	3
	4 p.m.		76	76	80	4
	6 p.m.		72	76	79	3
	8 p.m.		71	74	77	3
	10 p.m.	Showers	71	73	75	2
	12 midnight		70	72	73	1
May 26	2 a.m.		69	71	72	1
	4 a.m.		67	70	71	1
	6 a.m.		70	68	69	1
	8 a.m.	Clear	76	68	71	3
	10 a.m.		77	71	76	5
	12 noon		78	73	79	6
	2 p.m.		78	75	82	7
	4 p.m.		75	77	82	5
	6 p.m.		70	76	80	4
	8 p.m.		69	75	77	2
	10 p.m.		69	74	75	1
	12 midnight		68	72	73	1
May 27	2 a.m.	Clear	68	71	72	1
	4 a.m.		67	70	71	1
	6 a.m.		70	69	70	1
	8 a.m.		75	68	72	4
	10 a.m.		77	70	77	7
	12 noon		79	74	83	9
	2 p.m.		80	77	86	9
	4 p.m.		78	79	86	7
	6 p.m.		73	80	84	4
	8 p.m.		71	77	81	4
	10 p.m.		70	75	79	4
	12 midnight		70	74	76	2
May 28	2 a.m.		69	71	75	4
	4 a.m.		70	69	73	4
	6 a.m.		69	68	72	4
	8 a.m.	Clear	77	68	74	6
	10 a.m.		79	75	80	5
	12 noon		80	79	88	9
	2 p.m.		80	82	89	7
	4 p.m.		77	82	87	5
	6 p.m.		74	81	84	3
	8 p.m.		72	77	81	4
	10 p.m.		70	75	78	3
	12 midnight		69	73	76	3

TABLE 3

Soil temperatures at Wahiawa—July 23 to 30, 1923

DATE	HOUR	WEATHER	TEMPERATURE OF AIR	TEMPERATURE OF BARE SOIL	TEMPERATURE OF SOIL UNDER PAPER	DIFFERENCE DUE TO PAPER
			°F.	°F.	°F.	°F.
July 23	2 a.m.		72	78	79	1
	4 a.m.		72	76	78	2
	6 a.m.		71	75	76	1
	8 a.m.		75	75	76	1
	10 a.m.		79	76	80	4
	12 noon	Clear	80	77	83	6
	2 p.m.		82	79	88	9
	4 p.m.		81	81	90	9
	6 p.m.		77	81	89	8
	8 p.m.		75	77	86	9
	10 p.m.		74	75	83	8
	12 midnight		73	74	81	7
July 24	2 a.m.		72	72	80	8
	4 a.m.		70	71	77	6
	6 a.m.		68	70	76	6
	8 a.m.		76	72	76	4
	10 a.m.		80	75	82	7
	12 noon		84	79	89	10
	2 p.m.		82	82	93	11
	4 p.m.	Clear	81	82	91	9
	6 p.m.		77	81	88	7
	8 p.m.		74	78	86	8
	10 p.m.		74	76	83	7
	12 midnight		74	73	82	9
July 25	2 a.m.		73	72	80	8
	4 a.m.		71	71	78	7
	6 a.m.		70	70	77	7
	8 a.m.		77	71	77	6
	10 a.m.		82	75	84	9
	12 noon		85	80	94	14
	2 p.m.		85	84	97	13
	4 p.m.		83	87	95	8
	6 p.m.		78	87	92	5
	8 p.m.		74	82	89	7
	10 p.m.		74	81	86	5
	12 midnight		74	77	84	7
July 26	2 a.m.		73	76	83	7
	4 a.m.		72	75	81	6
	6 a.m.		73	75	80	5
	8 a.m.	Clear	78	74	81	7
	10 a.m.		82	75	87	12
	12 noon		84	79	95	16
	2 p.m.		84	82	97	15
	4 p.m.		82	86	95	9
	6 p.m.		76	88	92	4

TABLE 3—*Continued*

DATE	HOUR	WEATHER	TEMPERATURE OF AIR	TEMPERATURE OF BARE SOIL	TEMPERATURE OF SOIL UNDER PAPER	DIFFERENCE DUE TO PAPER
			°F.	°F.	°F.	°F.
July 26	8 p.m.		73	86	89	3
	10 p.m.		71	82	86	4
	12 midnight		71	77	84	7
July 27	2 a.m.		70	76	82	6
	4 a.m.		69	74	80	6
	6 a.m.		70	73	79	6
	8 a.m.		77	71	80	9
	10 a.m.	Clear	82	72	89	17
	12 noon		84	78	97	19
	2 p.m.		84	82	98	16
	4 p.m.		80	86	96	10
	6 p.m.		77	90	93	3
	8 p.m.		75	86	90	4
	10 p.m.		74	82	87	5
	12 midnight		72	81	85	4
July 28	2 a.m.		72	79	83	4
	4 a.m.		70	77	82	5
	6 a.m.		72	76	80	4
	8 a.m.		76	74	81	7
	10 a.m.		79	74	84	10
	12 noon		82	75	90	15
	2 p.m.	Clear	81	80	92	12
	4 p.m.		77	81	90	9
	6 p.m.		74	83	88	5
	8 p.m.		73	81	85	4
	10 p.m.		72	80	83	3
	12 midnight		71	77	81	4
July 29	2 a.m.		70	76	80	4
	4 a.m.		69	74	78	4
	6 a.m.		72	73	77	4
	8 a.m.		78	72	79	7
	10 a.m.		80	72	85	13
	12 noon		82	75	90	15
	2 p.m.		81	77	92	15
	4 p.m.		78	81	90	9
	6 p.m.		74	82	88	6
	8 p.m.		72	82	85	3
	10 p.m.	Cloudy and	72	81	83	2
	12 midnight	rain	71	77	81	4
July 30	2 a.m.		70	76	79	3
	4 a.m.		69	75	78	3
	6 a.m.		69	74	76	2
	8 a.m.		72	74	78	4
	10 a.m.		75	77	79	2
	12 noon		80	82	83	1

TABLE 4

Soil temperatures at Wahiawa—October 18 to 28, 1923

DATE	HOUR	WEATHER	TEMPERATURE OF AIR	TEMPERATURE OF BARE SOIL	TEMPERATURE OF SOIL UNDER PAPER	DIFFERENCE DUE TO PAPER
			°F.	°F.	°F.	°F.
October 18	2 p.m.		76	79	85	6
	4 p.m.		74	79	83	4
	6 p.m.		72	77	81	4
	8 p.m.		71	74	79	5
	10 p.m.		72	73	77	4
	12 midnight		71	72	76	4
October 19	2 a.m.	Clear	69	71	75	4
	4 a.m.		69	70	73	3
	6 a.m.		70	69	72	3
	8 a.m.		78	69	73	4
	10 a.m.		83	72	79	7
	12 noon		85	75	86	11
	2 p.m.		82	81	88	7
	4 p.m.		78	84	86	2
	6 p.m.	Rain	73	83	83	0
	8 p.m.		72	80	81	1
	10 p.m.		71	78	79	1
	12 midnight		70	76	77	1
October 20	2 a.m.		70	75	76	1
	4 a.m.		70	73	75	2
	6 a.m.		74	72	74	2
	8 a.m.		80	72	75	3
	10 a.m.	Clear	82	73	81	8
	12 noon		84	76	88	12
	2 p.m.		83	82	89	7
	4 p.m.		78	86	88	2
	6 p.m.	Rain	74	85	85	0
	8 p.m.		72	82	82	0
	10 p.m.		70	80	80	0
	12 midnight		70	77	78	1
October 21	2 a.m.		70	75	76	1
	4 a.m.		68	74	75	1
	6 a.m.		72	73	74	1
	8 a.m.		76	72	75	3
	10 a.m.		80	72	77	5
	12 noon		84	74	84	10
	2 p.m.		81	77	86	9
	4 p.m.		77	83	85	2
	6 p.m.		73	82	82	0
	8 p.m.	Rain	72	81	80	−1
	10 p.m.		71	79	78	−1
	12 midnight		70	75	76	1
October 22	2 a.m.		68	73	74	1
	4 a.m.	Rain	66	72	73	1
	6 a.m.		70	71	72	1

TABLE 4—*Continued*

DATE	HOUR	WEATHER	TEMPERATURE OF AIR	TEMPERATURE OF BARE SOIL	TEMPERATURE OF SOIL UNDER PAPER	DIFFERENCE DUE TO PAPER
			°F.	°F.	°F.	°F.
October 22	8 a.m.		78	69	73	4
	10 a.m.		79	69	76	7
	12 noon		78	77	80	3
	2 p.m.		76	76	81	5
	4 p.m.		77	75	81	6
	6 p.m.		74	74	79	5
	8 p.m.		72	73	78	5
	10 p.m.		71	72	76	4
	12 midnight		70	71	75	4
October 23	2 a.m.		68	69	73	4
	4 a.m.		67	69	72	3
	6 a.m.		68	68	71	3
	8 a.m.		79	70	72	2
	10 a.m.		82	74	78	4
	12 noon		83	77	83	6
	2 p.m.		82	81	86	5
	4 p.m.		77	82	85	3
	6 p.m.		74	81	83	2
	8 p.m.	Showers	71	79	81	2
	10 p.m.		70	76	78	2
	12 midnight		69	74	77	3
October 24	2 a.m.		67	73	75	2
	4 a.m.		65	72	73	1
	6 a.m.		67	69	72	3
	8 a.m.		78	69	73	4
	10 a.m.		83	73	79	6
	12 noon		84	77	86	9
	2 p.m.	Cloudy	83	85	88	3
	4 p.m.		79	85	87	2
	6 p.m.		74	83	84	1
	8 p.m.		72	80	82	2
	10 p.m.		70	78	79	1
	12 midnight		69	75	78	3
October 25	2 a.m.		70	74	76	2
	4 a.m.		69	73	75	2
	6 a.m.		71	72	74	2
	8 a.m.		75	72	76	4
	10 a.m.		80	74	77	3
	12 noon		72	75	79	4
	2 p.m.		77	76	81	5
	4 p.m.	Rain	75	77	81	4
	6 p.m.		72	76	79	3
	8 p.m.		70	74	77	3
	10 p.m.		69	73	75	2
	12 midnight		67	72	74	2

TABLE 4—*Continued*

DATE	HOUR	WEATHER	TEMPERATURE OF AIR	TEMPERATURE OF BARE SOIL	TEMPERATURE OF SOIL UNDER PAPER	DIFFERENCE DUE TO PAPER
			°F.	°F.	°F.	°F.
October 26	2 a.m.		66	71	73	2
	4 a.m.		65	70	71	1
	6 a.m.		65	69	70	1
	8 a.m.		73	67	70	3
	10 a.m.		80	69	73	4
	12 noon	Clear	83	73	80	7
	2 p.m.		81	77	85	8
	4 p.m.		79	80	85	5
	6 p.m.		74	80	83	3
	8 p.m.		71	78	80	2
	10 p.m.		71	75	78	3
	12 midnight		71	74	76	2
October 27	2 a.m.		69	73	74	1
	4 a.m.		69	72	73	1
	6 a.m.		70	71	72	1
	8 a.m.		77	70	71	1
	10 a.m.		79	70	75	5
	12 noon		82	72	80	8
	2 p.m.		81	77	84	7
	4 p.m.		79	81	85	4
	6 p.m.		75	82	83	1
	8 p.m.		73	79	81	2
	10 p.m.		73	77	79	2
	12 midnight		72	75	77	2
October 28	2 a.m.		72	74	75	1
	4 a.m.		72	73	74	1
	6 a.m.		71	72	73	1
	8 a.m.		75	71	73	2
	10 a.m.		75	71	74	3
	12 noon		78	73	76	3

ture of the day became somewhat higher, the nights were also appreciably warmer. This resulted in a greater difference in soil temperature between the mulched and unmulched plots, both in the daytime and at night. This is shown in table 3 for the last week in July. The same relative conditions prevailed during August and September. In October, broken showery weather was prevalent and the effect of this condition upon the soil temperatures is shown in table 4, for the period from October 18 to 28. During this time, there were frequent changes from bright sunshine to clouds, showers and rain.

The effect of weather upon the relative soil temperatures is more clearly shown during a rainy period in early December. The difference in temperature between the paper mulched plots and those with bare soil largely disappeared during the periods of heaviest precipitation, and occasional negative figures are shown in the column of differences. With sunshiny weather the

TABLE 5

Soil temperatures at Wahiawa—rainy weather November 30 to December 9, 1923

DATE	HOUR	WEATHER	TEMPERATURE OF AIR	TEMPERATURE OF BARE SOIL	TEMPERATURE OF SOIL UNDER PAPER	DIFFERENCE DUE TO PAPER
			°F.	°F.	°F.	°F.
November 30	2 a.m.		64	68	69	1
	4 a.m.		63	67	68	1
	6 a.m.		65	66	67	1
	8 a.m.		71	66	67	1
	10 a.m.		77	67	69	2
	12 noon		80	70	74	4
	2 p.m.		80	74	78	4
	4 p.m.		78	77	79	2
	6 p.m.		72	78	77	−1
	8 p.m.		68	75	75	0
	10 p.m.	Heavy	65	73	73	0
December 1	12 midnight	rains	61	70	71	1
	2 a.m.		64	68	69	1
	4 a.m.		63	67	68	1
	6 a.m.		63	66	67	1
	8 a.m.		70	66	67	1
	10 a.m.		73	67	68	1
	12 noon		76	68	70	2
	2 p.m.		78	71	73	2
	4 p.m.		77	73	75	2
	6 p.m.		71	74	74	0
	8 p.m.		68	73	72	−1
	10 p.m.	Rain	68	71	71	0
	12 midnight		68	69	70	1
December 2	2 a.m.		68	68	68	0
	4 a.m.		67	67	67	0
	6 a.m.		65	67	66	−1
	8 a.m.		70	66	67	1
	10 a.m.		79	66	69	3
	12 noon		81	68	73	5
	2 p.m.		82	73	78	5
	4 p.m.		78	76	79	3
	6 p.m.		73	78	77	−1
	8 p.m.	Rain	72	77	75	−2
	10 p.m.		71	74	73	−1
	12 midnight		70	73	72	−1
December 3	2 a.m.		68	72	70	−2
	4 a.m.		68	70	69	−1
	6 a.m.		65	68	68	0
	8 a.m.		73	67	68	1
	10 a.m.		80	76	71	−5
	12 noon		81	77	76	−1
	2 p.m.		78	76	79	3
	4 p.m.	Clear	76	74	79	5
	6 p.m.		72	73	77	4
	8 p.m.		72	72	76	4

TABLE 5—*Continued*

DATE	HOUR	WEATHER	TEMPERATURE OF AIR	TEMPERATURE OF BARE SOIL	TEMPERATURE OF SOIL UNDER PAPER	DIFFERENCE DUE TO PAPER
			°F.	°F.	°F.	°F.
December 3	10 p.m.		71	70	74	4
	12 midnight		70	70	72	2
December 4	2 a.m.		69	69	71	2
	4 a.m.		68	68	71	3
	6 a.m.		69	68	70	2
	8 a.m.		71	72	70	−2
	10 a.m.	Showers	76	73	71	−2
	12 noon		77	74	75	1
	2 p.m.		77	75	77	2
	4 p.m.		75	74	78	4
	6 p.m.		72	73	77	4
	8 p.m.	Clear	71	72	75	3
	10 p.m.		71	71	74	3
	12 midnight		70	69	73	4
December 5	2 a.m.		70	68	72	4
	4 a.m.		70	68	71	3
	6 a.m.		69	67	70	3
	8 a.m.		73	68	69	1
	10 a.m.		74	72	71	−1
	12 noon	Showers	76	73	73	0
	2 p.m.		76	73	75	2
	4 p.m.		74	72	75	3
	6 p.m.		71	71	74	3
	8 p.m.		70	69	72	3
	10 p.m.	Cloudy	69	68	71	3
	12 midnight		68	68	70	2
December 6	2 a.m.		68	67	70	3
	4 a.m.		67	66	69	3
	6 a.m.		68	66	68	2
	8 a.m.		69	67	68	1
	10 a.m.		73	69	70	1
	12 noon		75	73	72	−1
	2 p.m.	Showers	75	74	74	0
	4 p.m.		72	73	75	2
	6 p.m.		70	72	73	1
	8 p.m.		69	71	72	1
	10 p.m.		69	69	71	2
	12 midnight		69	68	70	2
December 7	2 a.m.		68	67	69	2
	4 a.m.		68	66	68	2
	6 a.m.		69	66	67	1
	8 a.m.		76	68	68	0
	10 a.m.		77	70	71	1
	12 noon		78	72	75	3
	2 p.m.		77	74	78	4

TABLE 5—*Continued*

DATE	HOUR	WEATHER	TEMPERATURE OF AIR	TEMPERATURE OF BARE SOIL	TEMPERATURE OF SOIL UNDER PAPER	DIFFERENCE DUE TO PAPER
			°F.	°F.	°F.	°F.
December 7	4 p.m.	Clear	73	74	78	4
	6 p.m.		72	72	76	4
	8 p.m.		70	70	74	4
	10 p.m.		69	69	73	4
	12 midnight		67	67	71	4
December 8	2 a.m.		65	66	69	3
	4 a.m.		64	65	68	3
	6 a.m.		64	66	67	1
	8 a.m.		74	67	68	1
	10 a.m.		79	68	71	3
	12 noon	Clear	80	72	75	3
	2 p.m.		79	75	78	3
	4 p.m.		75	75	79	4
	6 p.m.		69	73	76	3
	8 p.m.		69	71	74	3
	10 p.m.		69	69	72	3
	12 midnight		68	68	72	4
December 9	2 a.m.		68	68	71	3
	4 a.m.		67	67	70	3
	6 a.m.		67	67	69	2
	8 a.m.		73	68	70	2
	10 a.m.		78	71	75	4
	12 noon	Clear	81	73	79	6
	2 p.m.		80	76	83	7
	4 p.m.		74	78	82	4
	6 p.m.		70	76	79	3
	8 p.m.		68	74	76	2
	10 p.m.		68	72	74	2
	12 midnight		66	70	73	3

temperature rapidly rose in the paper mulched plots. The temperature differences in clear weather were approximately the same as those previously found during the spring months, that is, the paper plots were 4 to 5° warmer than those with bare soil during the early afternoon. The temperature differences during the night ranged from 2 to 3° during clear weather.

During the spring months the same general conditions prevailed. In clear weather the paper mulched plots were continuously higher in temperature than the plots of bare soil. During periods of comparative freedom from high wind, the differences between the mulched and unmulched plots were surprisingly constant, both during the day and night. Such a period of calm, clear weather from January 31 to February 7, 1924, is shown in table 6.

On May 1, 1924, the soil in the mulched and unmulched plots was thoroughly cultivated and pineapple plants were put in. Up to January 1, 1925, as the plants had not appreciably shaded over the plots, the temperature rela-

TABLE 6

Soil temperatures at Wahiawa—calm clear weather, January 31 to February 7, 1924

DATE	HOUR	WEATHER	TEMPERATURE OF AIR	TEMPERATURE OF BARE SOIL	TEMPERATURE OF SOIL UNDER PAPER	DIFFERENCE DUE TO PAPER
			°F.	°F.	°F.	°F.
January 31	2 p.m.		77	74	80	6
	4 p.m.		74	73	79	6
	6 p.m.		70	70	77	7
	8 p.m.		66	68	74	6
	10 p.m.	Clear	62	66	72	6
February 1	12 midnight		59	64	69	5
	2 a.m.		58	62	67	5
	4 a.m.		58	61	66	5
	6 a.m.		60	60	65	5
	8 a.m.		76	60	66	6
	10 a.m.		80	63	71	8
	12 noon		80	68	77	9
	2 p.m.	Clear	79	74	81	7
	4 p.m.		77	75	81	6
	6 p.m.		69	73	79	6
	8 p.m.		65	70	75	5
	10 p.m.		62	67	73	6
	12 midnight		65	66	71	5
February 2	2 a.m.		66	65	70	5
	4 a.m.		66	65	69	4
	6 a.m.		69	64	68	4
	8 a.m.		75	63	70	7
	10 a.m.		78	65	74	9
	12 noon	Clear	79	68	78	10
	2 p.m.		81	72	82	10
	4 p.m.		76	75	82	7
	6 p.m.		69	74	79	5
	8 p.m.		64	71	76	5
	10 p.m.		63	68	73	5
	12 midnight		63	66	71	5
February 3	2 a.m.		62	65	69	4
	4 a.m.		61	64	68	4
	6 a.m.		61	63	67	4
	8 a.m.		72	63	68	5
	10 a.m.	Clear	79	64	72	8
	12 noon		79	68	76	8
	2 p.m.		80	72	78	6
	4 p.m.		75	73	78	5
	6 p.m.		67	73	76	3
	8 p.m.		65	70	73	3
	10 p.m.		63	67	71	4
	12 midnight		63	66	69	3
February 4*	2 a.m.		64	65	68	3
	4 a.m.		64	64	68	4
	6 a.m.		66	63	67	4

* Week ending February 10, "Good weather all week; no rain but Kona wind and clouds."

TABLE 6—*Continued*

DATE	HOUR	WEATHER	TEMPERATURE OF AIR	TEMPERATURE OF BARE SOIL	TEMPERATURE OF SOIL UNDER PAPER	DIFFERENCE DUE TO PAPER
			°F.	°F.	°F.	°F.
February 4	8 a.m.		70	63	68	5
	10 a.m.		73	66	70	4
	12 noon		73	68	70	2
	2 p.m.	Clear	77	70	73	3
	4 p.m.		76	70	76	6
	6 p.m.		70	67	75	8
	8 p.m.		66	64	73	9
	10 p.m.		63	63	70	7
	12 midnight		60	62	68	6
February 5	2 a.m.		61	61	67	6
	4 a.m.		61	60	66	6
	6 a.m.		62	60	65	5
	8 a.m.		69	62	65	3
	10 a.m.		77	64	67	3
	12 noon		78	68	73	5
	2 p.m.		78	72	77	5
	4 p.m.		75	72	78	6
	6 p.m.		70	70	76	6
	8 p.m.		69	67	74	7
	10 p.m.		68	66	72	6
	12 midnight		68	65	71	6
February 6	2 a.m.		65	64	69	5
	4 a.m.		62	63	68	5
	6 a.m.	Clear	59	62	67	5
	8 a.m.		66	60	66	6
	10 a.m.		72	63	68	5
	12 noon		77	68	73	5
	2 p.m.		77	72	78	6
	4 p.m.		75	73	80	7
	6 p.m.		69	72	78	6
	8 p.m.		63	69	75	6
	10 p.m.		62	65	72	7
	12 midnight		64	64	70	6
February 7	2 a.m.		63	64	69	5
	4 a.m.		64	63	68	5
	6 a.m.		65	63	67	4
	8 a.m.		71	63	68	5
	10 a.m.		75	64	70	6
	12 noon	Clear	77	65	74	9
	2 p.m.		79	70	78	8
	4 p.m.		75	73	79	6
	6 p.m.		69	73	77	4
	8 p.m.		68	70	75	5
	10 p.m.		66	67	73	6
	12 midnight		63	66	71	5

tionships between the mulched and unmulched soils have continued to show the same differences on the paper and no paper soils. As this report closes with January, 1925, a longer period of time will be required to find whether the effect of the plants in shading the soil will greatly reduce the temperature differences between the mulched and unmulched plots.

Effect of paper mulch on moisture retention, ammonification, and nitrification

In order to study the effect of the paper mulch upon moisture retention and upon the development of ammonia and nitrates under field conditions, a series of plots was laid out at Wahiawa in May, 1924. Half of the plots were mulched with a heavy grade of asphalt impregnated and coated paper the same as that which had been used in the studies of soil temperature. One series of mulched and unmulched plots was untreated; a second series received ammonium sulfate at the rate of 1000 pounds per acre, supplying 208 pounds of nitrogen; a third series received mixed fertilizer at the rate of 1000 pounds per acre. The mixed fertilizer contained $11\frac{1}{2}$ per cent total nitrogen, of which 7.5 per cent was from ammonium sulfate and 4.0 per cent from dried blood. The mixed fertilizer also supplied $6\frac{1}{2}$ per cent phosphoric acid and 5 per cent potash. The plots were sampled after the soil was thoroughly prepared, the fertilizer was then worked in, the paper mulch was applied to the mulched plots, and the pineapple plants were put in. The first set of samples on May 9 at the beginning of the graphs therefore show the condition of the soil before it had received any treatment other than cultivation. Three sets of composite samples were collected from each plot. The figures plotted in the accompanying graphs are the average of the results obtained on the three composites collected from each plot. The subsamples of the composites analyzed were all taken to a depth of 1 foot.

The observations were continued from May 9, 1924, to December 11, 1924. This period of time covered a wide range of weather conditions and included the warmest summer months and the early winter season.

In order to make the figures obtained upon the various plots available for ready comparison, the data for moisture, nitrate nitrogen, and ammonia nitrogen are shown in the form of graphs. It may be stated that the results obtained upon the composite samples for moisture and nitrate nitrogen showed a significantly close agreement. The consistent course of the curves at all sampling periods is further evidence of the significance of the figures obtained. This was not the case with the figures for ammonia nitrogen. Here a very high variability was encountered; differences of over 100 per cent between composite samples were not unusual. The graphs for ammonia nitrogen are included; these also demonstrate that there is no consistent difference from which definite conclusions can be drawn.

It should be pointed out that the differences found in the soils of the paper and no paper plots will express only part of the differences caused by the paper

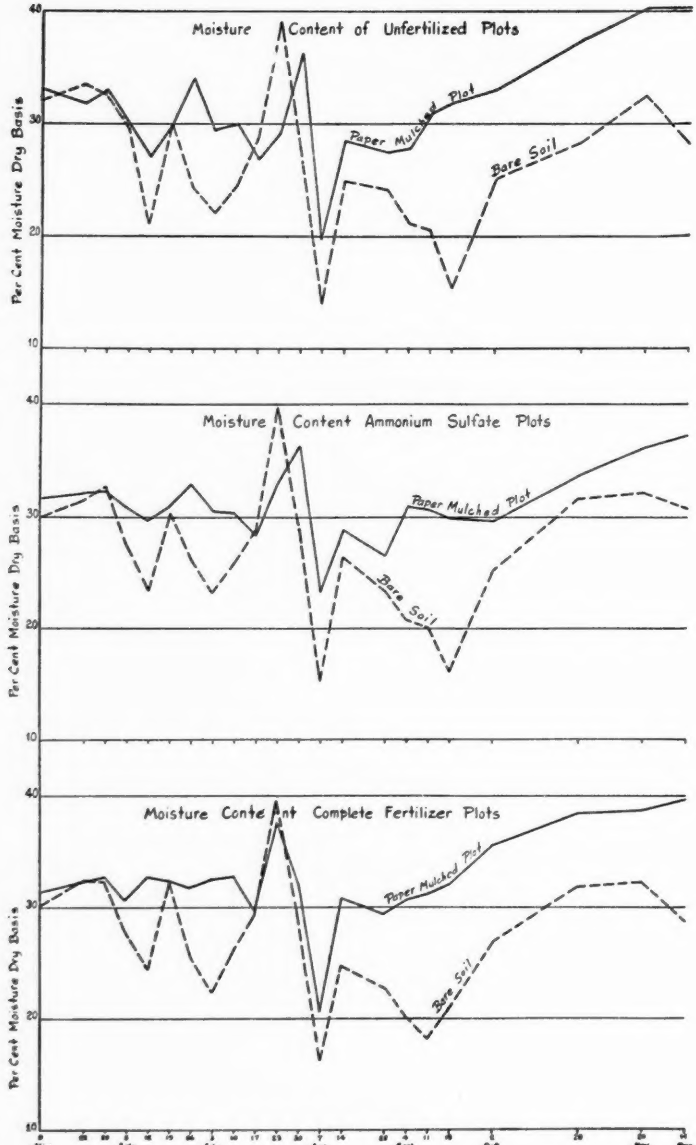

FIG. 2. MOISTURE CONTENT OF PAPER-MULCHED AND BARE SOIL PLOTS DURING THE FIRST 7 MONTHS' GROWTH

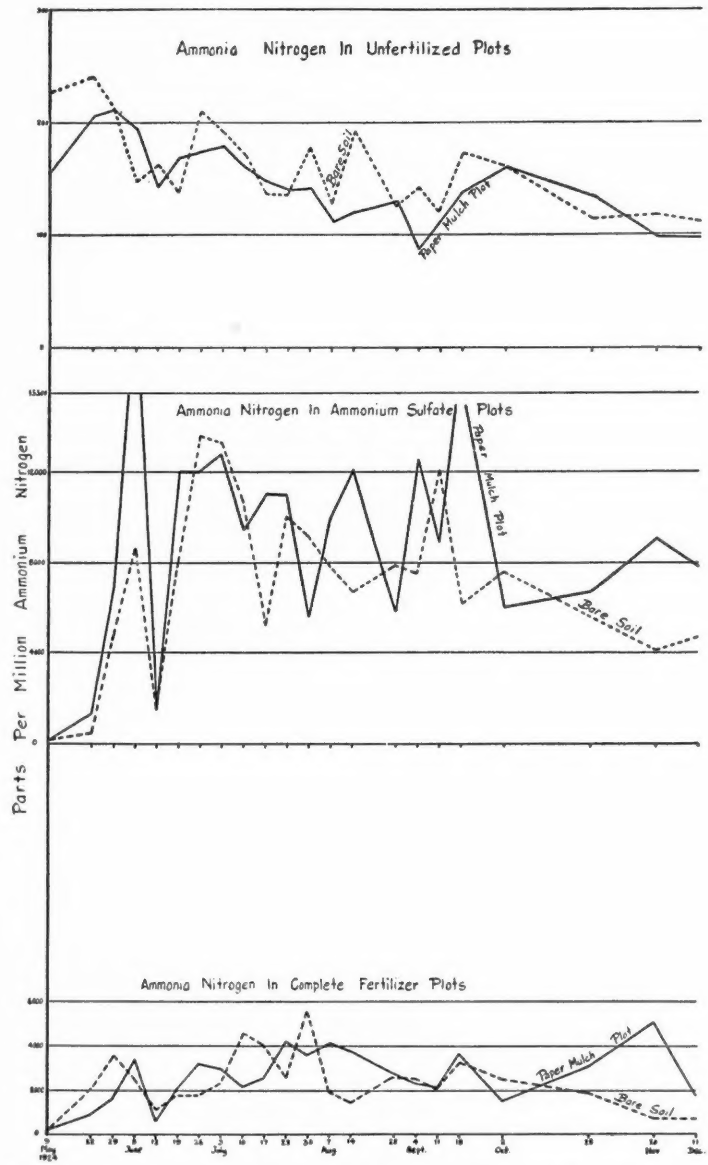

FIG. 3. AMMONIA NITROGEN CONTENT OF PAPER-MULCHED AND BARE SOIL PLOTS DURING THE FIRST 7 MONTHS' GROWTH

mulch. The pineapple plants themselves have been found by the authors in other work (3) to be 30 to 40 per cent larger by weight when grown under the paper mulch than in bare soil. This difference represents a notable extraction of moisture and nutrients from the soil. The authors are justified, there-

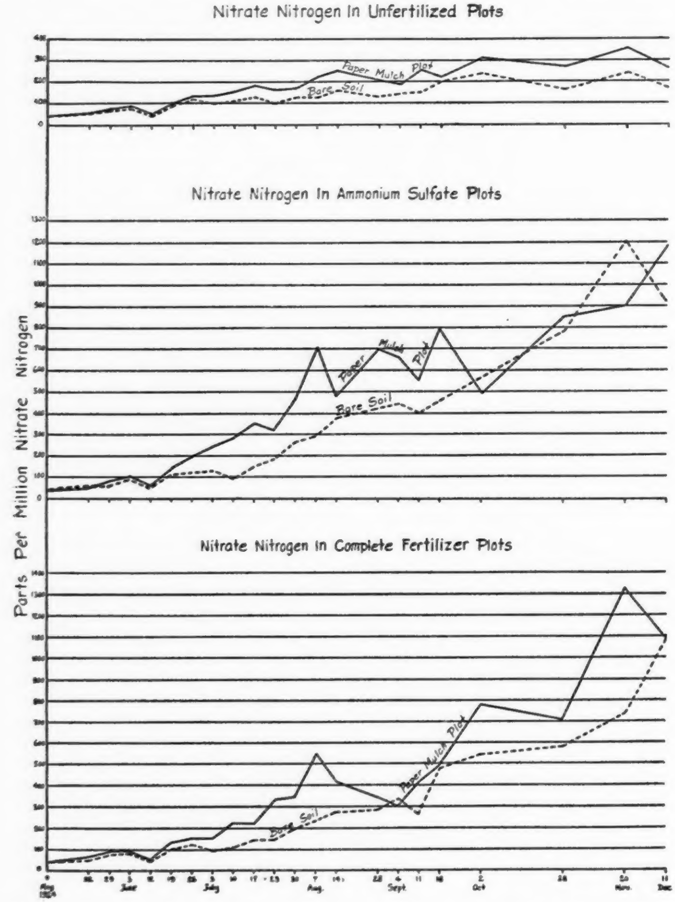

FIG. 4. NITRATE NITROGEN CONTENT OF PAPER-MULCHED AND BARE SOIL PLOTS DURING THE FIRST 7 MONTHS' GROWTH

fore, in believing that any balance of higher moisture or nutrients in the paper mulched soils would be larger still if allowance were made for the amounts of moisture and nutrients which go to nourish the larger plants.

The following analytical methods were employed. Moisture was deter-

mined by drying 100-gm. portions of soil over night at 100° to 103°C. Nitrates were determined by the phenoldisulfonic acid method on a portion of a 1 to 5 water extract. For the determination of ammonia nitrogen, an extensive study was made of a considerable number of aeration methods which have been proposed for the determination of ammonia in soils. These methods are essentially modifications of Folin's (1) aeration method for the determination of ammonia in physiological solutions. The Hawaiian soils have a large content of colloidal material consisting mainly of the hydrated oxides of iron and aluminum. These colloids have a high fixing power for ammonia and other radicals. We did not find it possible to recover by any of the aeration methods more than 40 to 50 per cent of the ammonia added to Wahiawa soil as ammonium sulfate. We were finally reduced to determining the ammonia in our samples by boiling 100 gm. of soil in a copper flask with 250 cc. of water and 5 gm. of magnesium oxide, the distillate being passed into standard acid. This method gave recoveries of approximately 90 per cent of the added ammonia, but we are, of course, well aware of the errors introduced by this method through the action of the magnesium oxide on the soil organic matter.

The results of the moisture determinations are presented in figure 2. The graphs show a consistently higher moisture content in the paper mulched soil. The only sampling period when this was not the case was on July 23, when rain fell just as the sampling of the plots was started. The results for this date show the rapid absorption of the rain in the bare soil, whereas the moisture had not had a chance to move away from the plants and borders of the plot in the paper mulched plot. Most of the moisture probably gains entrance to the paper mulched soil by the holes around the plants. Their leaves serve as excellent water collectors during rains or showers and conduct it down to the basal roots and so into the soil.

The figures for nitrate nitrogen are given in figure 3. Here again there was a consistently higher nitrate nitrogen content in all plots which were under the paper mulch.

The data on ammonia nitrogen are given in figure 4, but because of the variability previously noted in the figures obtained on the composite samples, the fluctuating content of ammonia nitrogen cannot be considered significant. It would require a special study to determine whether significant figures for this constituent could even be obtained by a large increase in the number of subsamples.

CONCLUSIONS

1. The foregoing results would appear to warrant the conclusion that the paper mulch exerts several effects upon Hawaiian soils planted to pineapples. Probably chief among these effects are a higher soil temperature, a higher content of soil moisture, and a more rapid elaboration of soil nutrients.

2. The temperature effect of the paper mulch varied with the weather and

with the season of the year, and will probably also vary with the degree of shading of the mulch paper by the pineapple plants.

3. The greatest increase in soil temperature due to mulching paper occurred in clear, bright weather. Showers and rain decreased the temperature differences between the mulched and the bare soil. In heavy rains the temperature differences disappeared and for short periods the bare soil appeared to be slightly warmer.

4. The maximum soil temperature generally occurred at 2:00 to 4:00 p.m., about 2 hours after the maximum air temperature.

5. The greatest differences between mulched and bare soils occurred during the warmest months of the year—in July, August, and September. These maximum temperature differences frequently amounted to 12 or 15°F. in the afternoon and decreased to about 4 or 5° in the night. During the winter months the maximum daytime differences in temperature generally ranged from 5 to 8°F. and decreased to 2 to 4° at night.

6. The effect of the paper mulch upon the retention of moisture in field soils was found to be appreciable. The paper mulched soils had a notably higher moisture content than the bare land.

7. A consistently higher nitrate content was found in paper mulched soils which had received no fertilizer as well as in those receiving ammonium sulfate and a complete mixture.

8. This higher nitrate content of paper mulched soils is taken to indicate that the paper mulch probably causes a more rapid elaboration of the principal soil nutrients in mulched soils.

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PLATE 1

Fig. 1. Method of laying the paper mulch.

Fig. 2. Newly planted field of pineapples, Experiment Station of Hawaiian Pineapple Canners' Association.

FIG. 1

FIG. 2

RESIDUAL EFFECTS OF FORTY YEARS CONTINUOUS MANURIAL TREATMENT: III. ULTIMATE FATE AND SOME PHYSICAL AND CHEMICAL EFFECTS OF APPLIED LIME

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Received for publication January 11, 1926

Data secured as the result of detailed studies of the plots which have received lime both as pulverized limestone and as burned lime show that in each case the limed soils at the end of 40 years of treatment contain more organic matter and nitrogen than the corresponding unlimed soils (8). The plot treated with limestone produced a total of 9560 pounds of dry matter in excess of that produced by the plot receiving the burned lime treatment. The soil treated with burned lime, however, contained 1087 pounds organic matter in excess of the limestone soil. The second paper of this series (11) shows that a close relationship exists between the total yields and the residual organic matter of similarly treated plots. On the basis of this established relationship it is computed that the limestone treatment has caused the decomposition of 9862 pounds of organic matter in excess of the untreated soil as compared to 4157 pounds where burned lime was used. In other words, bacterial action has been greater in the case of the limestone treatment. The difference in the effect of the two forms of lime is attributed to the variation in the actual amounts of available CaO applied and not to chemical differences between the two materials. The excess of available CaO applied as burned lime has apparently depressed bacterial action as compared to the coarse limestone treatment tending to reduce rather than stimulate the decay and ultimate loss of soil organic matter.

This paper deals with a study of the fate of the two forms of lime including the relative decomposition of the different grades of limestone particles. The results of certain laboratory studies, designed to show the effect of excess of lime on bacterial activity as measured by the evolution of CO_2 are also included. The data secured by Brown, MacIntire, and others as the results of earlier studies of these limed plots, dealing with the effect of lime on the physical and chemical properties of the soils, are presented and discussed.

BURNED LIME AND LIMESTONE TREATMENTS

Since 1881 burned lime has been applied both to the unfertilized soil and to the soil treated biennially with 6 tons of barnyard manure. Limestone has been applied only to the unfertilized soil. The burned lime has been applied

to each corn crop at the rate of 2 tons per acre. The limestone has been applied both to the corn and to the wheat crop at the rate of 2 tons per acre. From 1881 to 1921, therefore, 20 tons of burned lime and 40 tons of limestone have been applied. From 1881 to 1910 the burned lime was slaked in piles before spreading. Since 1910 raw ground lime has been used. During the first 27 years (1881–1908) very coarse limestone was applied, only 36.81 per cent of which would pass a 0.5-mm. screen. Since 1908 a much finer product has been used. Chemical examination of several composite samples of the lime shows that the burned lime was 88 per cent and the limestone 93.2 per cent pure. On the basis of the chemical composition the acre equivalent of 35,200 pounds of CaO was applied as burned lime and 41,754 pounds CaO as limestone.

The samples of soil used for the present study were taken from the west half of tier 4. This area was selected because the plots are level, thus avoiding any error due to surface washing. Samples were taken from both the surface (0–7 inches) and subsurface (7–14 inches).

TABLE 1

Mechanical composition of limestone used on plot 34 from 1881 to 1921

	1881–1908	1909–1915	1916–1917	1918–1921	1881–1921 AVERAGE	ACTUAL WEIGHT OF LIMESTONE	EQUIVALENT WEIGHT OF $CaCO_3$*
	Number of applications						
	14	3	1	2	20		
	per cent	*per cent*	*per cent*	*per cent*	*per cent*	*pounds*	*pounds*
Between 4 and 1 mm	48.34	0	2.50	16.00	35.56	28,450	26,515
Between 1 and 0.5 mm	14.85	0	4.00	22.40	12.83	10,268	9,590
Between 0.5 and 0.25 mm	16.15	11.38	5.50	30.10	16.31	13,038	12,151
Pass 0.25 mm	20.66	88.62	88.00	31.50	35.30	28,244	26,304
Total	100	100	100	100	100	80,000	74,560

* 93.2 per cent $CaCO_3$.

MECHANICAL ANALYSIS OF LIMESTONE USED FROM 1881 TO 1921

Four different grades of limestone were used during the progress of the experiment as shown in table 1. Of the limestone used (1881–1908) 70 per cent was very coarse only 20.66 per cent of which would pass a 0.25-mm. screen. Column 5 shows the approximate mechanical analysis for the entire period.

RECOVERY OF RESIDUAL LIMESTONE PARTICLES

The plot soil used for mechanical and chemical analysis represented the material that passed a 4-mm. screen instead of a 1-mm. screen as commonly used. The use of a coarse screen was necessary to avoid discarding the coarser limestone particles. The limestone treated soil (plot 34) and the nearest check

plot (plot 36) were then submitted to mechanical analysis using the soil that passed the 4-mm. screen. For several hours 400 gm. of soil were shaken with distilled water to which were added a few drops of ammonia. The material was then transferred to the 4-mm. screen to which were attached the several other screens in the order shown. The several separates were again washed, dried at 100°C., and weighed. The weight per acre of each mechanial separate was then computed on the basis of the weight of 1 mm. soil taken as 2,000,000 pounds per acre. The separates of both the limestone treated and the untreated soils were then finely ground and analyzed for total carbonates. The carbonates in excess of the untreated check soil are reported as residual limestone. Table 2 shows the proportions of recovered limestone in relation to the approximate amount applied from 1881–1921.

It is evident from a study of table 2 that the coarse limestone particles have undergone considerable change in their mechanical relationship. Of the 26,515

TABLE 2

Calcium carbonate applied to plot 34 and that recovered after forty years

	ACTUAL $CaCO_3$ APPLIED	WEIGHT OF SOIL PER ACRE		$CaCO_3$ RECOVERED		TOTAL $CaCO_3$ RECOVERED
		Surface 0–7 inches	Sub-surface 7–14 inches	Surface 0–7 inches	Sub-surface 7–14 inches	
	pounds	*pounds*	*pounds*	*pounds*	*pounds*	*pounds*
Between 4 and 1 mm.	26,515	113,200	113,200	11,501	797	12,298
Between 1 and 0.5 mm.	9,590	51,139	46,702	8,642	610	9,252
Between 0.5 and 0.25 mm.	12,151	143,125	115,915	25,047	1,462	26,509
Pass 0.25 mm.	26,304	1,805,726	1,837,383	8,062*	808*	8,870
Total	74,560	2,113,200	2,113,200	53,252	3,677	56,929

* By difference.

pounds that originally failed to pass a 1-mm. screen only 12,298 pounds remain. The increase in the proportion of particles between 0.5 and 0.25 mm. shows that these coarse materials have been reduced in size sufficiently to enable them to pass the 0.5-mm. screen. Of the original material that failed to pass the 0.25-mm. (100-mesh) screen 99.6 per cent was recovered. During the 40 years 17,631 pounds of carbonates have undergone decomposition. This loss of carbonates has been confined for the most part to the material that originally passed the 0.25-mm. screen. Of the 26,304 pounds of fine material applied, only 8870 pounds were recovered equivalent to a loss of 17,434 pounds. It is recognized that such a study can only approximate the truth and was undertaken with the hope of adding to our knowledge concerning the value of limestone of different degrees of fineness supplementary to previous studies (7).

FATE OF BURNED LIME AND LIMESTONE

Total CaO and inorganic CO_2 were determined on both the surface and subsurface samples representative of plots treated with burned lime and limestone. The same determinations were also made on the nearest untreated plots including also the plot treated with 6 tons of manure. The results secured are shown in table 3. The CaO and CO_2 results are corrected for that found in the unlimed plot 16 (manure), and check plots 24 and 36. Reference to table 3 shows that 87 per cent of the CaO applied in limestone remained in the surface soil at the end of 40 years as compared to 61 and 63 per cent in case of burned

TABLE 3
CaO found in the soil at the end of forty years

	1881–1921		
	Plot 22 (lime and manure)	Plot 23 (lime)	Plot 34 (limestone)
Total CaO applied (1881–1921) pounds per acre	35,200	35,200	41,754
*CaO recovered in surface soil (0–7 inches), per cent	1.005	1.010	1.720
Equivalent pounds per acre CaO	22,294	21,343	36,347
Total CaO lost from surface soil, pounds per acre	12,906	13,857	5,407
Per cent CaO lost of that applied	37	39	13
CaO recovered in subsurface* (7–14 inches) pounds per acre	7,715	9,620	3,487
CaO removed in crops, pounds per acre	836	502	550
CaO lost by drainage (by difference) pounds per acre	4,355	3,735	1,370
Inorganic CO_2, (surface soil) per cent	0.535	0.545	1.110
Equivalent to $CaCO_3$, pounds per acre	25,570	26,204	53,252
Per cent of CaO found present as $CaCO_3$	64	69	82
$CaCO_3$ decomposed, pounds per acre	......	......	17,631
Average annual decomposition of $CaCO_3$	......	......	441

* In excess of unlimed soil.

lime. The manure applied to plot 22 had apparently little effect on the loss or retention of lime as compared to plot 23 where lime was used alone. The lime found in the subsurface represented for the most part that which was carried down mechanically by the variation in depths of plowing. Examination of the subsurface soil by means of a strong magnifying glass disclosed particles of limestone and carbonated granules of burned lime not found in the unlimed soils. From 1881 to 1921 only 4045 pounds CaO were lost by drainage as an average of the two burned lime applications compared to 1370 pounds CaO applied as limestone. Of the total CaO found on the burned lime plot only 66.5 per cent was present as $CaCO_3$ as compared to 82 per cent where limestone was used. The computed loss of lime by drainage appears lower than would be expected. The average annual decomposition of $CaCO_3$ is approximately the same as that found on DeKalb soil (9). In previous studies

of this nature the loss of lime from the normal plowed surface has been attributed to solution and subsequent drainage, no corrections being made for that carried down mechanically by the plow and deposited in the lower stratum below the normal or average plowed depth. Thus on plot 23, 9620 pounds of CaO were found at a depth of from nine to twelve inches as the result of unusually deep plowing during the progress of the experiment. This amount is equivalent to 69 per cent of the total removed from the surface seven inches. In comparing the computed loss of lime by drainage from this soil with the results of other studies it should be borne in mind that the soil here is frozen for the major part of the non-growing seasons. The average air temperature from October to March is 34.33°F. The soil is a heavy limestone silt and clay loam not subject to excessive leaching. The excessive amounts of lime applied to this soil, perhaps alkaline at the beginning of the experiment, would greatly reduce the amount of carbonates decomposed as compared to smaller applications on an originally acid soil. MacIntire (5) in his study of the same plots in 1911 reports a considerably greater proportionate loss of lime. He, however, apparently discarded the soil material coarser than 1 mm. and also assumed that the lime used was chemically pure.

TABLE 4

Rate of limestone decomposition of soil from limestone treated plot compared with soils from check plots and plot treated with sulfate of ammonia

SOURCE OF SOIL USED	PLOT 32	PLOT 34	PLOT 36
40 year treatment	Sulfate of ammonia	Limestone	Untreated
Veitch lime requirement ($CaCO_3$)	5733	Alkaline	2525
Laboratory treatment (pounds per acre)	3 tons $CaCO_3$	3 tons $CaCO_3$	3 tons $CaCO_3$
Milligrams total CO_2 received in 30 days	1500.5	476.6	1024.8
Milligrams organic CO_2	976.4	471.4	802.5
Milligrams inorganic CO_2	524.1	6.2	222.3
Equivalent pounds per acre $CaCO_3$	5954	69	2525

To determine the rate of limestone decomposition on a heavily limed soil as compared to soils low in lime content, a laboratory experiment was conducted in which the equivalent of 6 tons of limestone was applied to 450 gm. of soils from the heavily limed plot 34 and to soils from the untreated plots and those that have received sulfate of ammonia. The soils were kept at optimum moisture content for 30 days in large filtering flasks to which were attached CO_2 trains. At regular intervals the CO_2 evolved was absorbed in weighed soda lime tubes in the usual way. Table 4 shows the total milligrams of CO_2 collected from each soil. From the known organic and inorganic CO_2 content of the original treated soils the proportions of the CO_2 derived from the two sources are computed. The data included in table 4 show that the rate of limestone decomposition on the heavily limed soil was only 1 per cent of that on

the sulfate of ammonia treated soil and less than 3 per cent of that on the check plot soil. The decomposition of soil organic matter also proceeded more slowly on the limestone plot soil.

Chemical and Physical Effects of Lime

The effect on soil reaction. Hydrogen-ion studies were made on each of the limed plots of the four tiers by the electrometric method. Since the burned lime was applied only to the corn ground it was possible to study the progressive changes in soil reaction in relation to the length of time between lime applications. Table 5 shows the data secured as the result of these studies. These data show that the soil 3 months after the CaO was applied has practically the same OH-ion concentration as the soil to which the CaO had been applied 39 months previous. The two burned lime treatments show an average OH-ion concentration of 7.87 as compared to 7.68 on the limestone treated soil. The manure treatment has had no significant effect on the soil reaction. These

TABLE 5

Effect of burned lime and limestone on soil reaction

	PLOT 22 (LIME AND MANURE)				PLOT 23 (LIME)				PLOT 34 (LIMESTONE)			
	Tier 1	Tier 2	Tier 3	Tier 4	Tier 1	Tier 2	Tier 3	Tier 4	Tier 1	Tier 2	Tier 3	Tier 4
Number months since last lime application	15	3	39	27	15	3	39	27	15	3	23	11
Hydrogen-ion concentration	7.76	7.91	7.81	7.85	7.89	7.96	7.95	7.89	7.79	7.66	7.63	7.64

TABLE 6

Water-soluble nitrates and organic matter recovered on burned lime plot 23 and check plot 24

(Parts per million)

	TIER 1		TIER 2		TIER 3		TIER 4	
	Plowed oats stubble		Corn		Grass sod		Wheat stubble	
	Plot 23	Plot 24	Plot 23	Plot 24*	Plot 23	Plot 24	Plot 23	Plot 24†
Nitrates (NO_3)	47.0	34.2	32.8	49.8	16.1	3.7	17.0	8.6
Total solids	378	195	380	260	325	150	420	200
Volatile matter	200	105	199	145	160	80	230	95
Inorganic CO_2 (in dry residue)	38.8	20.0	45.0	15.0	33.8	2.0	26.3	1.0
Equivalent $CaCO_3$	88.2	45.4	102.3	34.1	76.8	4.5	59.8	2.3
Organic CO_2 (in dry residue)	135.0	67.7	77.5	43.0	85.0	66.3	86.3	65.0
Equivalent organic matter	63.4	31.8	36.4	20.2	39.9	31.2	40.6	30.9

* Received 2 tons limestone 1922.

† Received 3 tons limestone 1923.

data are contrary to the results secured by Hoagland and Christie (4) who report the long duration of a high OH-ion concentration on soils treated with caustic lime.

Effect of lime on water-soluble nutrients. Plots 23 (CaO) and 24 (check)[1] of each tier were sampled September 18, 1925. Water-soluble nitrates (NO_3), total solids, volatile matter, and organic and inorganic CO_2 were determined on the aqueous extracts prepared according to the method of the Bureau of Soils.[2] The CO_2 was determined in the dry residue (total solids) obtained by evaporating in a suitable flask, aliquot of the clear water extract using the chromic acid method of White and Holben (10). The data secured from this study are shown in table 6. The burned lime plot 23 shows an excess of nitrates except on tier 2. In every instance with the exception of NO_3 on tier 2 the burned lime treated soil exceeds the check plot in water-soluble material. The burned lime plots show 36.8 per cent soluble organic matter in excess of the check plots. The two check plots on tiers 2 and 4, however, which have each received 3 tons of limestone show less soluble organic matter than the unlimed check plots of tiers 1 and 3.

EARLIER STUDIES OF BROWN AND MACINTIRE

In 1910 Brown and MacIntire (2) made a detailed study of water soluble nutrients of nine plots of tier 2. Included in the plots were those that have received burned lime with and without manure and the nearest check plot 24 and plot 16 treated with manure without lime. These studies included the determinations of nitrates (NO_3), potassium, calcium, total solids, volatile matter, and total moisture. These determinations were made on samples taken at eighteen periods during the 1910 growing season. The data shown in table 7 have been recomputed from parts per million to a percentage relation where the results are expressed on the basis of the unlimed plots taken as 100. Thus if the unlimed plot shows 8.9 p.p.m. and the limed soil 9.2 p.p.m., the data are expressed as 103. This method of presentation, commonly used, avoids the necessity of including the actual unlimed data and aids in a rapid study of the relationship between the two treatments. A study of table 7 shows that as a general average there are no significant differences between the limed and unlimed plots with respect to the accumulation of nitrates. However, from May 6 to June 17 there appears a seasonal difference in the favor of the unlimed soil. For the remainder of the season the limed soils with a few exceptions exceed in nitrates. A study of the potassium data shows that there is no evidence that lime has increased the solubility of potassium compounds. The water-soluble calcium is greatly in excess on the limed plots. Lime used alone apparently slightly increased the water holding capacity, however, when

[1] From 1881 to 1921 no lime was used except on plots 22, 23, and 34. Beginning with 1922 all plots of tier 2 and 1923 tier 4 were treated with limestone except the plots previously limed and also two PK plots.

[2] U. S. Dept. Agr. Bur. Soils Bul. 31.

used with manure the limed plot shows the opposite effect. The volatile matter is in excess on both limed plots. On the basis of the data shown in table 6 the volatile matter on the CaO treated soils varies between 17 and 31

TABLE 7

*Effect of lime on water soluble nutrients**

On the basis of the unlimed soils taken as 100

DATE SAMPLED	LIME (CaO) ALONE					LIME (CaO) AND MANURE				
	NO_3	K	Ca	H_2O	Volatile matter	NO_3	K	Ca	H_2O	Volatile matter
1910										
May 6.........	101	...	273	100	144	96	...	632	94	221
May 13.........	91	95	229	100	190	63	97	503	92	214
May 17.........	68	93	327	108	224	54	110	386	95	267
May 25.........	86	107	429	98	...	91	110	665	92	...
June 2.........	70	124	458	103	167	98	84	547	91	232
June 9.........	70	95	512	100	331	71	37	469	93	282
June 17.........	95	81	517	113	300	79	118	913	102	124
June 23.........	117	122	553	100	189	128	88	527	92	129
June 27.........	86	67	532	104	303	119	130	724	97	198
July 6.........	240	100	588	105	100	155	94	628	100	199
July 12.........	110	84	517	106	364	115	161	748	93	352
July 19.........	112	132	620	97	146	120	109	712	98	257
July 26.........	100	109	304	87	303	91	75	585	109	175
August 3.......	115	65	480	93	274	83	51	655	97	159
August 17.......	152	76	439	93	143	121	80	534	88	118
August 31.......	100	65	390	100	150	89	90	445	104	115
September 13....	88	75	437	105	280	72	136	486	98	170
September 30....	77	95	417	103	185	121	26	211	95	103

* Studies made by Brown and MacIntre in tier 2, 1910. This tier was in oats in 1910.

TABLE 8

Volatile matter extracted by various organic solvents

On the basis of the unlimed soil taken as 100

	EACH SAMPLE SEPARATELY EXTRACTED		SUCCESSIVE EXTRACTIONS	
	Plot 22* (lime and manure)	Plot 23 (lime)	Plot 22 (lime and manure)	Plot 23 (lime)
Ether.......................................	61	108	45	90
Acetone....................................	89	76	27	39
Chloroform................................	31	100	106	150
Ethyl acetate.............................	64	77	92	108
Alcohol....................................	60	76	103	103

* Compared with plot 20 (10 tons manure) instead of plot 16 (6 tons manure).

per cent organic matter or an average of 23 per cent. The volatile matter on the two unlimed check plots shows 30 and 39 per cent organic matter compared

to 14 and 32 per cent on the limed check plots of tiers 2 and 4. Although there is necessarily a variation in the proportions of organic matter in the volatile material it is evident that the lime treatment has increased the water-soluble organic matter.

Volatile matter ("organic matter") extracted by various organic solvents. In 1909–1910 Brown, MacIntire, and Cree (3) conducted detailed studies of samples taken from tier 2 on October 11, 1909. Included in these studies were several experiments designed to determine the effect of lime on the solubility of "organic matter" in various organic solvents. The studies were carried out by means of the extraction apparatus devised by Wiley.[3] The data given

TABLE 9

*Analytical classification of nitrogen in decomposition products formed by digestion of soils and humus with acid**

(In per cent of total nitrogen in soil and humus respectively)

PLOT NUMBER	PLOT TREATMENT	AMMONIA-N	HUMIN NITROGEN			AMINO ACID NITROGEN	
			Soluble	Insoluble	Total	Monoamino	Diamino
	By acid digestion of soil						
20	10 tons manure	21.64	28.32	26.29	54.61	8.63	12.97
22	6 tons manure and lime	18.39	25.36	28.02	53.38	17.48	9.04
23	Lime	16.32	31.77	29.09	60.86	12.80	8.21
24	Untreated	16.05	26.39	29.40	55.79	17.80	8.82
	By acid digestion of humus						
20	10 tons manure	6.74	4.03	30.05	34.08	34.78	19.65
22	6 tons manure and lime	4.69	6.55	34.16	40.71	44.89	7.51
23	Lime	6.47	6.71	31.04	37.71	45.22	8.41
24	Untreated	10.63	5.69	19.65	25.34	55.02	7.29

* Studies made by Brown and Lathrop.

in table 8 were obtained by extracting each soil for 7 hours. Two different methods of extraction were used. In one case each sample of soil was separately extracted, in the second case the same sample of soil was successively extracted in the order given.

The data in table 8 show that lime has reduced the solubility of volatile matter in the various solvents. The nature of the volatile matter was not determined; however, it is no doubt largely organic materials.

THE FORMS OF ORGANIC NITROGEN IN LIMED AND UNLIMED PLOTS

Brown and Lathrop (1) using soil samples taken in 1909 from a number of plots of tier 2 made a detailed study of the forms in which the organic nitrogen

[3] Space will not permit a detailed account of the various experiments. The reader is therefore referred to the original papers.

occurs in the soil. The studies included: (*a*) treating the fine soil (0.5 mm.) with boiling acid, (*b*) treating humus prepared from these soils with boiling acid, and (*c*) heating the soils with water under pressure. The detailed methods used are included in the original article. Table 9 shows the results secured from a study of two limed and unlimed soils. A study of the results of Brown and Lathrop shown in table 9 brings out some interesting data concerning the effect of lime on the nitrogen compounds of the four soils. This is especially true in case of the soils of plots 23 and 24. There is a higher percentage of humin nitrogen on the limed plot 23, which according to the authors represents the unavailable portion of the total nitrogen. The mono-amino acid nitrogen is present in the unlimed soil in a much greater proportion. The data secured on plots 20 and 22 are not comparable since the two plots have received different proportions of manure. The humus studies show that the unlimed humus of plot 24 contains 62.31 per cent of its total nitrogen as amino

TABLE 10

Composition of alkali soluble humus

Per cent of ash free humus

	CARBON	HYDROGEN	OXYGEN	NITROGEN
Limed soil plot 23	52.12	5.80	38.709	3.371
Unlimed soil plot 24	41.20	6.10	49.893	2.806

acid nitrogen as compared to 53.63 per cent where lime was used. In other words, a larger proportion of the total humus nitrogen on the unlimed soil is potentially available for plant growth. A comparison of the availability of the humus nitrogen and total soil nitrogen shows that a much greater proportion of the humus nitrogen was converted into amino acid or available nitrogen material. From these figures we may conclude that the soil nitrogen associated with the alkali-soluble organic matter represents the more readily available organic nitrogen, and further that the effect of lime has been to reduce the availability of the humus nitrogen as measured by a larger proportion of humin nitrogen, and to reduce correspondingly the amino acid nitrogen.

COMPOSITION OF HUMUS FROM THE LIMED AND UNLIMED SOILS

Brown and Lathrop (1) included in their studies a detailed analysis of the humus derived from the limed and unlimed soils of plots 23 and 24 respectively. The original data are included in the same paper. Table 10 shows the results of this interesting study. The humus of the two soils shows a marked difference in composition. The humus of the limed soil shows a higher percentage of carbon and nitrogen.

PHYSICAL EFFECTS OF LIME

A limited number of physical studies have been made on these old plots with reference to the effect of lime. The studies reported by Brown, MacIntire, and Cree (3) have been confined for the most part to the determinations of the

TABLE 11

*Effect of lime on the behaviour of soil moisture**

Computed on basis of the unlimed soil taken as 100

	PLOT 23 (LIMED)	PLOT 24 (UNLIMED)
Apparent specific gravity	101	100
Water-holding capacity	96	100
Rate of downward movement of water:		
1 hour	437	100
5 days	227	100
11 days	207	100
Hydroscopic moisture	99	100
Water-absorbing capacity (7 days)	106	100
Moisture in field soil:		
October 22	82	100
October 29	102	100
October 4	92	100
October 10	103	100
October 24	94	100
December 1	100	100

* Studies of Brown and MacIntire.

TABLE 12

Effect of lime on soil structure as indicated by the draft of a plow

(On the basis of the unlimed soil taken as 100)

	HAY SOD			CORN STUBBLE			OATS STUBBLE		
	Tier 1 (1912)	Tier 2 (1913)	Tier 3 (1914)	Tier 4 (1912)	Tier 1 (1913)	Tier 2 (1914)	Tier 3 (1911)	Tier 4 (1912)	Tier 1 (1913)
Plot 23 (lime)	90	98	102	100	97	100	100	100	92
Plot 24 (no lime)	100	100	100	100	100	100	100	100	100
Plot 16 (manure)	100	100	100	100	100	100	100	100	100
Plot 22 (lime and manure)	99	97	99	98	97	107	91	100	93

effect of lime on the behaviour of soil moisture including: (*a*) water holding capacity, (*b*) hygroscopic moisture, (*c*) water absorbing capacity, and (*d*) rate of movement (drainage). Noll in 1912, 1913, and 1914 (6) determined the effect of the various manurial treatments on soil structure as measured by the plow draft. Tables 11 and 12 show a summary of these data. The results are

expressive on the percentage basis in which the unlimed soils are taken as 100. The moisture studies with the exception of the drainage data show no significant effect of lime on this soil. The rate of downward movement of soil water is shown to be over twice as rapid where lime has been applied.

The data in table 12 indicate that the draft of the plow has been somewhat reduced on plot 23 as compared to the unlimed soil of plot 24. On hay sod the average value is 96.7, on corn stubble, 99, and on oats stubble, 97.3. The lime used on plot 23 has apparently reduced the plow draft by 2.3 per cent as measured by a standard dynamometer. When lime was used with manure as compared to manure alone the average values are as follows: hay sod, 98.3, corn stubble, 100, and oats stubble, 94.7, equivalent to a general average of 97, or a reduction of the plow draft of 2.2 per cent. In only two out of eighteen trials did the lime soil show a heavier draft than the unlimed soil.

SUMMARY

The first three papers of the series dealing with a study of these old fertilizer plots have been confined largely to a study of the effect of lime on soil organic matter, including also certain studies made prior to 1921. It is the plan of the authors of this series to include when possible the results of the earlier studies which are now published in the annual reports of the College farm from 1899 to 1912. These earlier studies correlated with 1921 data are especially valuable in determining the progressive changes in these differently treated plot soils.

Fate of burned lime and limestone (1881–1921)

1. From 1881 to 1921 a total of 20 tons of burned lime were applied to plots 22 and 23 and 40 tons of limestone were applied to plot 34 (acre basis).
2. It is estimated on the basis of the chemical composition of the two lime materials that 35,200 pounds per acre CaO was applied as burned lime and 41,754 pounds CaO as limestone.
3. From 1881 to 1921, 64.4 per cent of the limestone used failed to pass a 0.25-mm. (100-mesh) screen. From 1881 to 1908, 79.34 per cent of the limestone applied was retained on a 0.25-mm. screen.
4. Examination of the limestone treated soil at the end of 40 years of continuous treatment showed that 17,631 pounds of carbonates had undergone decomposition.
5. The loss of carbonates was found to be confined to the fine material that originally passed a 0.25-mm. screen (of the 17,631 pounds of total $CaCO_3$ decomposed, 17,434 pounds represented the very fine material).
6. Of the total CaO applied as burned lime 63 per cent of that used on the manured land was recovered in the surface soil as compared to 61 per cent where the lime was applied to the untreated soil.
7. It is estimated that of the 12,906 pounds CaO lost from the surface soil (0–7 inches) of plot 22 (lime and manure), 7715 pounds were lost mechanically

by being plowed down below the normal plowed depth, 836 pounds were removed in crops, and 4353 pounds were lost by drainage.

8. Where the burned lime was used without manure, of the 13,857 pounds CaO lost from the surface 7 inches, 9620 pounds were carried down mechanically by the plow, 502 were removed in crops, and 3735 pounds were lost by drainage.

9. On the land treated with limestone, only 13 per cent of the CaO was lost from the surface 7 inches. Of the 5407 pounds of CaO lost from the surface 7 inches, 3487 pounds were carried down below that depth by plowing, 550 pounds were removed in crops, and 1370 pounds were lost by drainage.

10. From the above figures it is shown that the actual loss of CaO from the normal plowed depth is not necessarily confined to that removed by drainage, in fact, only 33.8 per cent of the CaO lost from plot 22 is attributed to solution and subsequent drainage as compared to 27 per cent on plot 23 and 25.3 per cent on plot 34.

11. Of the total CaO found in the surface soil, 64 per cent on plot 22, 69 per cent on plot 23, and 82 per cent on plot 34 are present as $CaCO_3$.

12. The relatively low loss of lime from this soil during the forty years of continuous cropping may be due to several factors: (*a*) that the soil was no doubt alkaline at the beginning of the experiment, (*b*) that the soil is a heavy silt to clay loam not subject to excessive drainage, and (*c*) that during the non-growing season (October to March inclusive) the average air temperature at this station is 34.3°F. The soil therefore during the non-growing season is not subject to the same degree of bacterial activity as a soil farther south would be.

13. The relative decomposition of limestone on three differently treated soils is shown in table 4. The sulfate of ammonia treated soil decomposed the equivalent of 5954 pounds per acre $CaCO_3$ in 30 days as compared to 2525 pounds on the untreated check plot soil and only 69 pounds on the soil treated with limestone for forty years. It is thus shown that the rate of limestone decomposition is influenced by the soil reaction that is, the relative supply of lime present.

Chemical and physical effects of lime

14. Hydrogen-ion studies show that the soil treated with burned lime has an average OH-ion concentration of 7.88 compared to 7.68 where limestone was applied.

15. Three months after burned lime was applied, the OH-ion concentration was 7.91 as compared to 7.81, 39 months after lime application. Lime has therefore not maintained a high OH-ion concentration on this soil.

16. The burned lime soil of tiers 1 and 3 contained as an average 63.7 per cent water-soluble organic matter and 66.4 per cent nitrates in excess of those on the unlimed check plot 24 of the same tiers.

Results of earlier studies

17. Studies made on these plots in 1910, including the determinations of water-soluble nutrients each week during the growing season, show that from

May 6 to June 27 the limed soil was deficient in nitrates as compared to the unlimed soil. During the remainder of the season the limed soil showed nitrates in excess of the unlimed soil.

18. Studies of water-soluble nutrients during seventeen periods of the growing season show that lime has had a tendency to reduce the water-soluble potassium by 7.1 per cent when used alone and 6.7 per cent when used with manure.

19. The studies of Brown and Lathrop show that lime has had the effect of increasing the proportion of humin or unavailable nitrogen in the soil and soil humus. The humus from the limed soil is also higher in percentage of carbon and nitrogen.

20. Studies of Brown, MacIntire, and Cree on the effect of the various treatments on the physical properties of the soil, show by laboratory experiments that lime apparently increases the rate of downward movement of soil water and reduces slightly the water-holding capacity of this soil. Moisture studies made in the field, however, show that there is no measurable effect of lime on the water-holding capacity of the same soils.

21. The field studies of Noll on the effect of the various treatments on the tilth or soil structure show that lime has somewhat reduced the plow draft. Lime used alone (plot 23) has reduced the plow draft 2.3 per cent and lime with manure (plot 22), 2.2 per cent.

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CONCENTRATION OF CARBONATES IN TWO MINNESOTA SOIL TYPES[1]

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Received for publication, December 29, 1925

INTRODUCTION

In the summer of 1923 when field work was commenced on a detailed soil survey of Lac qui Parle County, one of the Minnesota counties bordering South Dakota, the writer frequently observed in freshly made roadcuts a pronounced zone of carbonate accumulation, this being best developed on the well-drained upland. Lac qui Parle County lies in the glacial and loessial soil province of the United States in which the Barnes, confined to regions of low to moderate rainfall, is recognized as being one of the most prominent series. It has developed on calcareous glacial drift under grassland vegetation and has a dark brown to black surface soil with gray to brownish yellow, fine textured, highly calcareous subsoil. Its most outstanding characteristic, as recognized by the Bureau of Soils, is that when the soil has reached a mature development, there is a zone of carbonate accumulation at some horizon of the soil profile.

As no experimental data have been published showing the distribution or amount of carbonate in its profile an investigation was undertaken to determine how the carbonate content varied from the surface downward and especially how much more was present in the concentration zone than above and below.

The immediate surface of this soil is usually leached of carbonates and is slightly acid by the Truog test. Vigorous effervescence with dilute hydrochloric acid is usually encountered not more than about 16 or 18 inches below the surface, although in some places the subsoil to a depth of 30 inches will not effervesce. The carbonates in the subsoil may be uniformly distributed or may be collected in masses, often in well defined concretions.

As only a small part of the county had been surveyed at the time the samples used in this study were taken, no effort was made to confine the sampling to any particular soil types but 13 exposures were selected in which the carbonate accumulation was very evident. The soil survey of the county having since been completed, it has been found that two important types are

[1] Published with the approval of the Director as Paper no. 588 of the Journal Series of the Minnesota Agricultural Experiment Station.

TABLE 1

Effervescence and carbonate content of the soil profile sections

The heavy lines indicate the upper and lower limits of the light gray color of the soils

Barnes silty clay loam

DEPTH	PROFILE I		PROFILE II		PROFILE III		PROFILE IV		PROFILE V		PROFILE VI		PROFILE VII		AVERAGE
	Effervescence	Carbonate	Effervescence	Carbonate	Effervescence	Carbonate	Effervescence	Carbonate	Effervescence	Carbonate	Effervescence	Carbonate	Effervescence	Carbonate	
inches		*per cent*		*per cent*		*per cent*		*per cent*		*per cent*		*per cent*		*per cent*	*per cent*
1–3	0	0.4	v. sli.	2.0	v. sli.	1.1	mod.	5.0	v. sli.	3.2	v. sli.	1.5	0	0.4	2.0
4–6	0	0.2	sli.	2.6	v. sli.	0.9	mod.	4.1	sli.	2.7	v. sli.	1.0	0	0.4	1.7
7–9	0	0.5	sli.	2.5	v. sli.	0.9	str.	9.8	sli.	3.0	v. sli.	1.4	0	0.4	2.7
10–12	0	0.4	str.	15.7	mod.	4.1	str.	16.8	str.	12.5	v. sli.	1.4	0	0.4	7.3
13–15	str.	26.6	str.	23.0	str.	17.3	str.	29.6	str.	17.7	sli.	2.3	0	0.3	16.8
16–18	str.	33.4	str.	30.0	str.	27.5	str.	35.2	str.	24.1	mod.	7.5	0	0.4	22.7
19–21	str.	23.9	str.	28.0	str.	30.7	str.	35.5	str.	25.7	str.	25.3	sli.	2.7	24.6
22–24	str.	25.5	str.	25.3	str.	26.6	str.	31.1	str.	25.0	str.	22.1	str.	20.0	25.1
25–27	str.	13.0	str.	23.9	str.	23.2	str.	24.3	str.	20.7	str.	23.4	str.	25.3	22.0
28–30	str.	14.1	str.	21.1	str.	20.2	str.	22.1	str.	24.3	str.	22.7	str.	27.1	21.7
31–33			str.	21.4	str.	16.8	str.	22.7	str.	22.1	str.	18.6	str.	27.3	21.5
34–36			str.	21.8	str.	17.3	str.	12.1	str.	17.3	str.	19.8	str.	29.6	19.7
37–39					str.	17.1			str.	15.9	str.	13.4	str.	18.9	16.4
40–42					str.	15.9			str.	15.7	str.	22.3	str.	18.6	
43–45											str.	17.7			
Av. 1st foot....		0.4		5.7		1.7		8.9		5.4		1.3		0.4	
Av. 2nd foot...		27.4		26.6		25.5		32.9		23.1		14.3		5.9	
Av. 3rd foot...		13.6*		22.1		19.4		20.3		21.1		21.1		27.3	

* Average of 2 sections.

0 = none; sli. = slight; mod. = moderate; str. = strong; v. = very.

Unnamed silt loam

DEPTH	PRO.ILE VIII		PROFILE IX		PROFILE X		PROFILE XI		PROFILE XII		PROFILE XIII		AVERAGE
	Efferves-cence	Carbonate	Efferves-cence	Carbonate	Efferves-cence	Carbonate	Efferves-cence	Carbonate	Efferves-cence	Carbonate	Efferves-cence	Carbonate	
inches		*per cent*		*per cent*		*per cent*		*per cent*		*per cent*		*per cent*	*per cent*
1–3	v. sli.	2.5	v. sli.	2.5	0	0.4	0	1.4	sli.	4.5	0	0.7	2.0
4–6	v. sli.	2.5	v. sli.	2.3	0	0.2	0	2.0	sli.	3.4	v. sli.	2.5	2.1
7–9	mod.	3.5	v. sli.	1.6	sli.	0.7	0	1.8	sli.	2.7	v. sli.	2.5	2.2
10–12	str.	14.8	v. sli.	2.3	sli.	0.4	0	2.5	mod.	4.5	v. sli.	2.5	4.5
13–15	str.	23.9	str.	19.4	sli.	1.4	0	2.5	v. sli.	2.5	0	2.7	8.7
16–18	str.	27.3	str.	30.5	mod.	2.7	0	2.0	v. sli.	2.7	v. sli.	2.5	11.3
19–21	str.	29.1	str.	29.6	str.	21.6	0	2.0	sli.	4.5	v. sli.	3.0	15.0
22–24	str.	25.3	str.	24.1	str.	30.5	mod.	4.6	str.	21.1	v. sli.	2.7	18.1
25–27	str.	18.4	str.	20.5	str.	30.7	str.	34.3	str.	24.0	str.	10.2	23.0
28–30	str.	17.8	str.	21.6	str.	30.5	str.	45.5	str.	32.1	str.	25.9	28.9
31–33	str.	17.5	str.	24.3	str.	29.6	str.	39.1	str.	36.4	str.	31.1	29.6
34–36	str.	16.6	str.	25.3	str.	20.9	str.	35.7	str.	27.1	str.	30.5	26.0
37–39			str.	28.9			str.	30.9	str.	21.6	str.	26.6	
40–42			str.	30.0			str.	26.8	str.	21.5	str.	21.6	
43–45			str.	29.6			str.	22.7					
46–48			mod.	10.0			str.	20.9					
49–51			mod.	7.7									
Av. 1st foot......		5.8		2.2		0.4		1.9		3.8		2.1	
Av. 2nd. foot.....		26.4		25.9		14.0		2.8		7.7		2.7	
Av. 3rd. foot.....		17.6		22.9		27.9		38.6		29.9		24.4	

0 = none; sli. = slight; mod. = moderate; str. = strong; v. = very.

represented in the samples collected, one the Barnes silty clay loam, the other a silt loam of apparently loessial origin, but unnamed, as final correlation has not yet been made by the United States Bureau of Soils. This type, as found in Lac qui Parle County, may be described as follows:

> The surface soil to a depth of 8 inches consists of a black to very dark brown silt loam which has a single grain or silty structure and is loose and friable. This is underlain to a depth of 14 inches by a dark brown horizon somewhat finer in texture and more compact than the surface layer. The next, or third horizon, which extends to a depth of 24 inches, has a yellowish brown color distinctly lighter than the horizon immediately overlying it. Its texture is finer, being a silty clay loam or silty clay, and the material comprising it is compact, somewhat tough, and quite plastic when wet. These three upper horizons have been leached of their carbonates. The fourth, the zone of carbonate concentration, begins abruptly below the heavy horizon and extends to a depth of 34 inches, having a thickness of from 4 to 8 inches. It consists of loose, friable silty material ranging in color from light yellowish gray to almost white and contains lime concretions. Below this layer is a friable, yellowish brown silty clay loam which is uniformly calcareous and has no concretions of lime.

Six of the sets taken are from this type and seven from the Barnes.

METHOD OF SAMPLING

Samples were taken only at places where a careful preliminary examination showed a distinct zone of carbonate accumulation. As it is certain that not all the mature soils of these series have zones with so much carbonate, the locations selected may represent those of maximum accumulation, and areas of these types may be found with little or no accumulation. When a satisfactory profile had been found, a fresh vertical face was exposed, by cutting back into the bank with a spade, and this smoothed and then marked off into 3-inch sections to a depth that in most cases extended below the distinct zone of carbonate accumulation. Commencing with the lowest marked section, in order to avoid any contamination from the overlying soil, and working upward, using a small garden trowel, samples were taken every 3 inches. About 3 pounds of soil was removed from each section, placed in a pail, and thoroughly mixed. A sample of this was removed, placed in a sack, and shipped to the laboratory. After being allowed to become thoroughly air dry it was passed through a 2-mm. sieve, any portion remaining on this being removed and pulverized in a porcelain mortar, a rubber tipped pestle being used. All pebbles and stones were discarded. Frequently small concretions of calcium carbonate, more than 2 mm. in diameter, composed a part of the sample. These were not discarded with the pebbles, but, being considered part of the carbonate concentration, were crushed and included in the fine material used for the CO_2 determination.

All the samples were taken the latter part of September, 1923.

METHOD OF CARBONATE DETERMINATION

In order to determine the carbon dioxide content, a small weighed quantity of the finely divided sample was placed in a small flask and treated with a

measured volume of standard 0.1 N hydrochloric acid solution. After vigorous evolution of gas had ceased, the vessel was gently warmed over a flame until all reaction had stopped. The excess, or unneutralized acid, was determined by titrating with a 0.1 N solution of sodium hydroxide and the percentage of carbonate calculated. As all the carbonate is assumed to have been present as calcium carbonate, the computed percentages of carbonate are reported on this basis.

Table 1 gives the percentage of carbonate and the effervescence for each 3-inch section of each profile for both soil types. Figures 1 and 2 show the vertical distribution of carbonate by 3-inch sections.

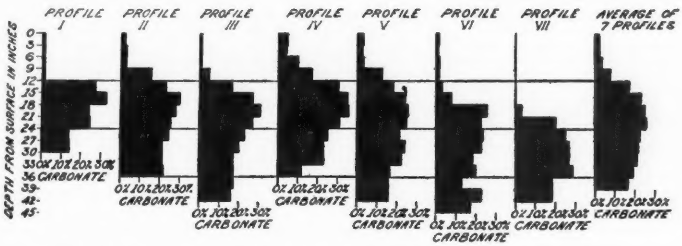

FIG. 1. DISTRIBUTION OF CARBONATE IN BARNES SILTY CLAY LOAM

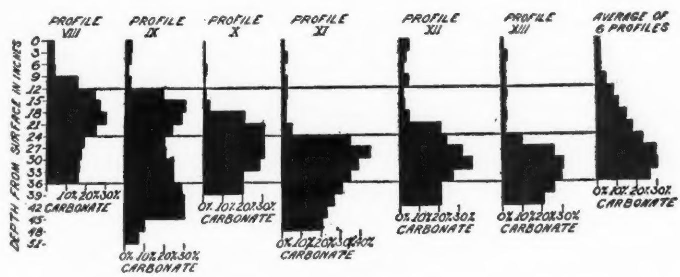

FIG. 2. DISTRIBUTION OF CARBONATE IN UNNAMED SILT LOAM

DISCUSSION

It will be seen from figures 1 and 2, that in every profile there is a pronounced zone of carbonate accumulation, occurring relatively close to the surface in some cases and deeper in others. In a soil derived from parent glacial material of high carbonate content it is difficult to decide definitely, in the case of some of the profiles, at just what depth the carbonate accumulation commences, and even more difficult to decide where it ends. This is particularly true of profiles IV, V, and VIII. With profile IV the carbonate content begins to increase 6 inches below the surface and for each additional

3-inch section it increases until it reaches its maximum at a depth of 18 inches, from which point it gradually diminishes until at 34 inches it is about the same as at 9 inches. The maximum accumulation in the Barnes silty clay loam is found at an average depth of 21 inches, whereas in the unnamed silt loam it occurs at a slightly greater depth—about 30 inches. In some of the profiles considerable carbonate is present even in the immediate surface layers, as 3.2, 5.0 and 4.5 per cent in the first 3-inch sections of profiles V, IV, and XII. Its presence here, however, does not seem to influence the depth at which the concentration zone occurs nor does it, when compared with the other profiles, appear to increase or diminish the total amount present in that zone. The profile showing the most pronounced accumulation is that of XI (fig. 2), in the 21–24-inch section of which there is only 4.6 per cent of carbonate, whereas in the section immediately below there is 34.3 per cent, reaching its maximum of 45.5 per cent in the next 3-inch section, and from this gradually dropping until at a depth of 48 inches there is only 20.9 per cent. In practically all cases as the zone is approached from the surface there is a very abrupt rise in the carbonate content but as the point of maximum accumulation is passed the drop is more or less gradual. Exceptions to this, however, are noted in profiles IX and XII where there is a more pronounced break. An interesting feature is to be observed in profile IX (fig. 2) in which it will be seen that two concentration zones occur, the upper one beginning at 15 inches below the surface and the lower one at a depth of 40 inches. Both these zones were plainly visible, having concretions of carbonate embedded throughout the soil mass.

For both of the soil types the average content of carbonate in the successive 3-inch sections was computed, this being shown at the extreme right in figures 1 and 2. From these it will be seen that the irregularities, so pronounced in each individual profile, have been largely eliminated and in each there is a more gradual rise and fall of the carbonate, but with the zone of accumulation standing out prominently with each type.

In this connection it is of interest to note the very large amount of carbonate present in these two types. At the point of maximum accumulation the carbonate content ranges from 25.3 to 45.5 per cent and in the substratum of parent material, below the zone of accumulation, the carbonate content ranges from 7.7 to 22.7 per cent.

RELATION OF CARBONATE CONTENT TO TEXTURE

Five of the sets showing pronounced concentration zones were subjected to moisture-equivalent determinations in order to see whether any relation existed between the carbonate content and the texture. As this zone in all cases lies below the surface soil and well away from the influence of the large proportion of organic matter which characterizes the surface of these types and greatly affects the moisture equivalent, the values may be assumed to give a single-valued expression of texture and therefore to be directly

comparable one with another. If the high content of carbonate in some of the sections were instrumental in either decreasing or increasing the moisture equivalent this would have been brought out. In table 2 are shown the percentages of carbonates in these profiles and the moisture equivalents. Apparently no direct relation exists between the two values, the texture remaining practically constant both above and below the zone of carbonate accumulation. However, in the case of one profile, no. I, the moisture equivalent is highest at the point of maximum accumulation and falls off rather sharply below this.

TABLE 2

Moisture equivalents and calcium carbonate for 5 soil profiles

DEPTH	BARNES SILTY CLAY LOAM						UNNAMED SILT LOAM			
	Profile I		Profile III		Profile IV		Profile X		Profile XII	
	Moisture equivalent	Calcium carbonate	Moisture equivalent	Calcium carbonate	Moisture equivalent	Calcium carbonate	Moisture equivalent	Calcium carbonate	Moisture equivalent	Calcium carbonate
inches		*per cent*		*per cent*		*per cent*		*per cent*		*per cent*
1–3	26.8	0.4	36.1	1.1	33.3	5.0	32.8	0.4	29.9	4.5
4–6	24.3	0.2	31.2	0.9	30.6	4.1	32.9	0.2	30.3	3.4
7–9	22.4	0.5	28.6	0.9	32.3	9.8	28.1	0.7	30.0	2.7
10–12	22.9	0.4	26.6	4.1	31.5	16.8	27.7	0.4	28.3	4.5
13–5	27.1	26.6	25.3	17.3	33.9	29.6	26.9	1.4	25.9	2.5
16–18	32.7	33.4	27.7	27.5	34.8	35.2	27.7	2.7	25.9	2.7
19–21	26.7	23.9	28.8	30.7	34.3	35.5	27.2	21.6	23.7	4.5
22–24	12.4	25.5	27.5	26.6	31.5	31.1	28.5	30.5	21.4	21.1
25–27	8.9	13.0	26.7	23.2	28.7	24.3	29.7	30.7	21.3	24.0
28–30	9.1	14.1	26.1	20.2	25.3	22.1	30.1	30.5	23.9	32.1
31–33			26.4	16.8	18.5	22.7	31.5	29.6	27.1	36.4
34–36			27.3	17.3	19.6	12.1	28.8	20.9	25.2	27.1
37–39			26.9	17.1					23.8	21.6
40–42			26.2	15.9						21.5

RELATION OF CARBONATE CONTENT TO COLOR

Because of the high percentage of carbonate in the concentration zone and its pronounced whitish color, as observed in the field at the time of sampling, color comparisons of the samples collected were made in order to determine whether any close relation existed between the carbonate content and the color. For this purpose small samples from each section of every profile were placed on trays and arranged in order of depth. Four color groups, consisting of (*a*) black to very dark brown, (*b*) grayish brown, (*c*) light gray to light yellowish gray and (*d*) yellowish gray, were chosen as being those into which all the soils could be grouped. The surface layers of all profiles, ranging in depth from 9 to 32 inches, were dark and therefore were placed in groups a and b. As depth increased, the change from dark to light was, in nearly all profiles, abrupt, the color becoming light gray to light yellowish

gray, and as this was passed the soil became a distinct yellowish gray. The light gray to light yellowish gray color of the soils is indicated in table 1 by heavy, black lines placed at the points where the gray color was first observed and where it ended. It will be seen that these lines inclose the sections comprising the concentration zones and agree very closely with these as shown in figures 1 and 2.

In the case of profile IX which has the double zone, it will be seen that the 22–33 sections, although containing a relatively high percentage of carbonate, are not enclosed in the lines; the soils of these sections were distinctly yellow in color.

DEGREE OF EFFERVESCENCE

The degree to which the soils effervesced when treated with hydrochloric acid was determined for all 3-inch sections of each profile. Approximately 5 gm. of air-dry soil was placed on a watch glass and about 10 cc. of dilute hydrochloric acid added. The degree to which the soils effervesced is indicated in table 1 as slight, moderate, and strong. It will be seen that there is a very close agreement between the degree of effervescence of each section of all profiles and the carbonate content. In the case of each profile there was very strong effervescence in the sections of maximum carbonate content although there also was strong effervescence in the layers above and below the zone if the carbonate content exceeded 10 per cent.

If five degrees of effervescence be recognized, the following values show the maxima, minima, and average:

DEGREE OF EFFERVESCENCE	NUMBER OF SAMPLES SHOWING THIS	CARBONATE CONTENT		
		Maxima	Minima	Average
		per cent	*per cent*	*per cent*
None	21	2.7	0.2	1.0
Very slight	23	3.2	0.9	2.1
Slight	13	4.5	0.4	2.6
Moderate	9	10.0	2.7	5.5
Strong	110	45.5	9.8	23.7

SUMMARY

Two important soil types in western Minnesota, at depths varying from 12 to 27 inches below the surface, show zones of pronounced carbonate accumulation, in which lime concretions are thickly distributed and in which the carbonate content ranges from 25.3 to 45.5 per cent. In the unaltered material below, it varies from 7.7 to 22.7 per cent.

No direct relation was found between the carbonate content and the fineness of texture of the subsoil.

In the sections of carbonate concentration the color was distinctly grayer than in those above and below.